APPENDIX E

Technical Background Report
to the Safety Element of the La Quinta
2035 General Plan Update
Seismic Hazards, Geologic Hazards, Flooding Hazards

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TECHNICAL BACKGROUND REPORT to the SAFETY ELEMENT of the

La Quinta 2035
GENERAL PLAN UPDATE

RIVERSIDE COUNTY, CALIFORNIA

SEISMIC HAZARDS
GEOLOGIC HAZARDS
FLOODING HAZARDS

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TECHNICAL BACKGROUND REPORT TO THE SAFETY ELEMENT UPDATE
CITY of LA QUINTA, CALIFORNIA

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CHAPTER 1: SEISMIC HAZARDS

Earthquake-triggered geologic effects include ground shaking, surface fault rupture, landslides, liquefaction, subsidence, tsunamis and seiches. Some of these hazards can occur in the city of La Quinta, as discussed in detail below. Earthquakes can also lead to reservoir failures, urban fires, and toxic chemical releases.

In seismically active southern California, an earthquake has the potential to cause far-reaching loss of life or property, and economic damage. This is because damaging earthquakes are relatively frequent, affect widespread areas, trigger many secondary effects, and can overwhelm the ability of local jurisdictions to respond. Although it is not possible to prevent earthquakes, their destructive effects can be minimized. Comprehensive hazard mitigation programs that include the identification and mapping of hazards, prudent planning, public education, emergency exercises, enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures can significantly reduce the scope of an earthquake's effects and avoid disaster. The record shows that local government, emergency relief organizations, and residents can and must take action to develop and implement policies and programs to reduce the effects of earthquakes. Thus, this document not only discusses the potential seismic hazards that can impact La Quinta, but also provides action items and programs that can help the City become more self-sufficient in the event of an earthquake.

1.1 Seismic Context – Earthquake Basics

The outer 10 to 70 kilometers of the Earth consist of enormous blocks of moving rock called ***tectonic plates***. There are about a dozen major plates, which slowly collide, separate, and grind past each other. In the uppermost brittle portion of the plates, friction locks the plate edges together, while plastic movement continues at depth. Consequently, the near-surface rocks bend and deform near plate boundaries, storing strain energy. Eventually, the frictional forces are overcome and the locked portions of the plates move. The stored strain energy is then released in seismic waves that radiate out in all directions from the rupture surface causing the Earth to vibrate and shake as the waves travel through. This shaking is what we feel in an earthquake. Most earthquakes occur on or near plate boundaries. Southern California has many earthquakes because it straddles the boundary between the North American and Pacific plates, and fault rupture accommodates their motion.

By definition, the break or fracture between moving blocks of rock is called a ***fault***, and such differential movement produces a fault rupture. Few faults are simple, planar breaks in the Earth. They more often consist of smaller strands, with a similar orientation and sense of movement. A strand is mappable as a single, fairly continuous feature. Sometimes geologists group strands into segments, which are believed capable of rupturing together during a single earthquake. The more extensive the fault, the bigger the earthquake it can produce. Therefore, multi-strand fault ruptures produce larger earthquakes.

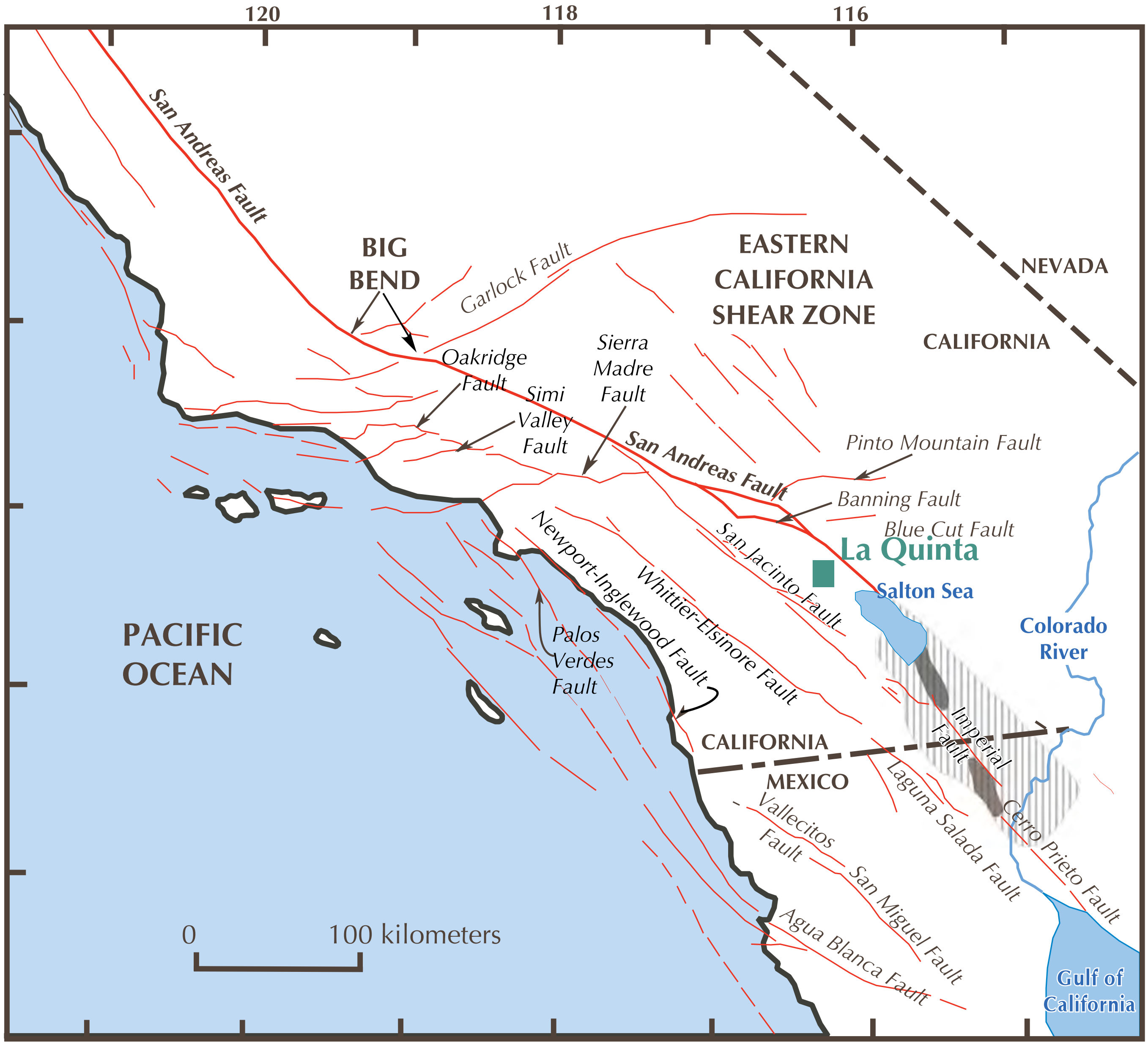
Total ***displacement*** is the length, measured in kilometers (km), of the total movement that has occurred along a fault over as long a time as the geologic record reveals. It is usually estimated by measuring distances between geologic features that have been split apart and separated (offset) by the cumulative movement of the fault over many earthquakes. ***Slip rate*** is a speed, expressed in millimeters per year (mm/yr). Slip rate is estimated by measuring an amount of offset accrued during a known amount of time, obtained by dating the ages of geologic features. Slip rate data also are used to estimate a fault's earthquake recurrence interval. Sometimes referred to as "repeat time" or "return interval," the ***recurrence interval*** represents the average amount of time that elapses between major earthquakes on a fault. The most specific way to derive the recurrence interval for a given fault is to excavate trenches across the fault to obtain ***paleoseismic*** evidence of earthquakes that have occurred during prehistoric time. Paleoseismic studies show that faults with high slip rates generally have shorter recurrence intervals between major earthquakes. This is so because a high slip rate indicates rocks that, at depth, are moving relatively quickly, and the stored energy trapped within the locked, surficial rocks needs to be released in frequent (geologically speaking), large earthquakes.

The city of La Quinta, and most of the western part of southern California, is riding on the Pacific Plate, which is moving northwesterly (relative to the North American Plate), at about 50 millimeters per year (mm/yr), or about 165 feet in 1,000 years. This is about the rate at which fingernails grow, and seems unimpressive. However, it is enough to accumulate enormous amounts of strain energy over tens to thousands of years. Despite being locked in place most of the time, in another 15 million years (a short time in the context of the Earth's history), due to plate movements, Los Angeles (which, like La Quinta, is on the Pacific Plate) will be almost next to San Francisco (which is on the North American Plate).

Although the San Andreas fault marks the main separation between the Pacific and North American plates, only about 60 to 70% of the plate motion actually occurs on this fault. The rest is distributed along other faults of the San Andreas system, including the San Jacinto, Whittier-Elsinore, Newport-Inglewood, Palos Verdes, and several offshore faults. To the east of the San Andreas fault, slip is distributed among faults of the Eastern California Shear Zone, including those responsible for the 1992 M_W 7.3 Landers and 1999 M_W 7.1 Hector Mine earthquakes. (M_W stands for ***moment magnitude***, a measure of earthquake energy release, discussed further below.) Thus, the zone of plate-boundary earthquakes and ground deformation covers an area that stretches from Nevada to the Pacific Ocean (see Figure 1-1).

Because the Pacific and North American plates are sliding past each other, with relative motions to the northwest and southeast, respectively, all of the faults mentioned above trend northwest-southeast, and are strike-slip faults. On average, ***strike-slip faults*** are nearly vertical breaks in the rock, and when a strike-slip fault ruptures, the rocks on either side of the fault slide horizontally past each other. However, there is a kink in the San Andreas fault commonly referred to as the "Big Bend," located about 185 miles northwest of La Quinta (Figure 1-1). Near the Big Bend, the two plates do not slide past each other. Instead, they collide, causing localized compression, which results in folding and thrust faulting. ***Thrusts*** are a type of dip-slip fault where rocks on opposite sides of the fault move up or down relative to each other. When a thrust fault ruptures, the top block of rock moves up and over the rock on the opposite side of the fault.

In southern California, ruptures along thrust faults have built the Transverse Ranges geologic province, a region with a unique east-west trend to its landforms and underlying geologic structures that is a direct consequence of the plates colliding at the Big Bend. Many of southern California's most recent damaging earthquakes have occurred on thrust faults that are uplifting the Transverse Ranges, including the 1971 M_W 6.7 San Fernando, 1987 M_W 5.9 Whittier Narrows, 1991 M_W 5.8 Sierra Madre, and 1994 M_W 6.7 Northridge earthquakes. Thrust faults in southern California have been particularly hazardous because many are "***blind***;" that is, they do not extend to the surface of the Earth, and have therefore been difficult to detect and study before they



Source: Modified from Fuis and Mooney, 1990.

MAP EXPLANATION

Fault

Onshore Spreading Center

New Crust (late Cenozoic)

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Project Number: 3004
Date: 2010

Regional Fault Map

Figure 1-1

rupture. Some earthquakes in southern California, including the 1987 Whittier Narrows earthquake and the 1994 Northridge earthquake, occurred on previously unknown blind thrust faults. As a result, a great amount of research in the last 15 years has gone into learning to recognize subtle features in the landscape that suggest the presence of a buried thrust fault at depth, and developing techniques to confirm and study these structures. Some geologists have started to develop paleoseismic data for these buried thrust faults, including recurrence interval, estimates of the maximum magnitude earthquake these faults are capable of generating, and displacement per event.

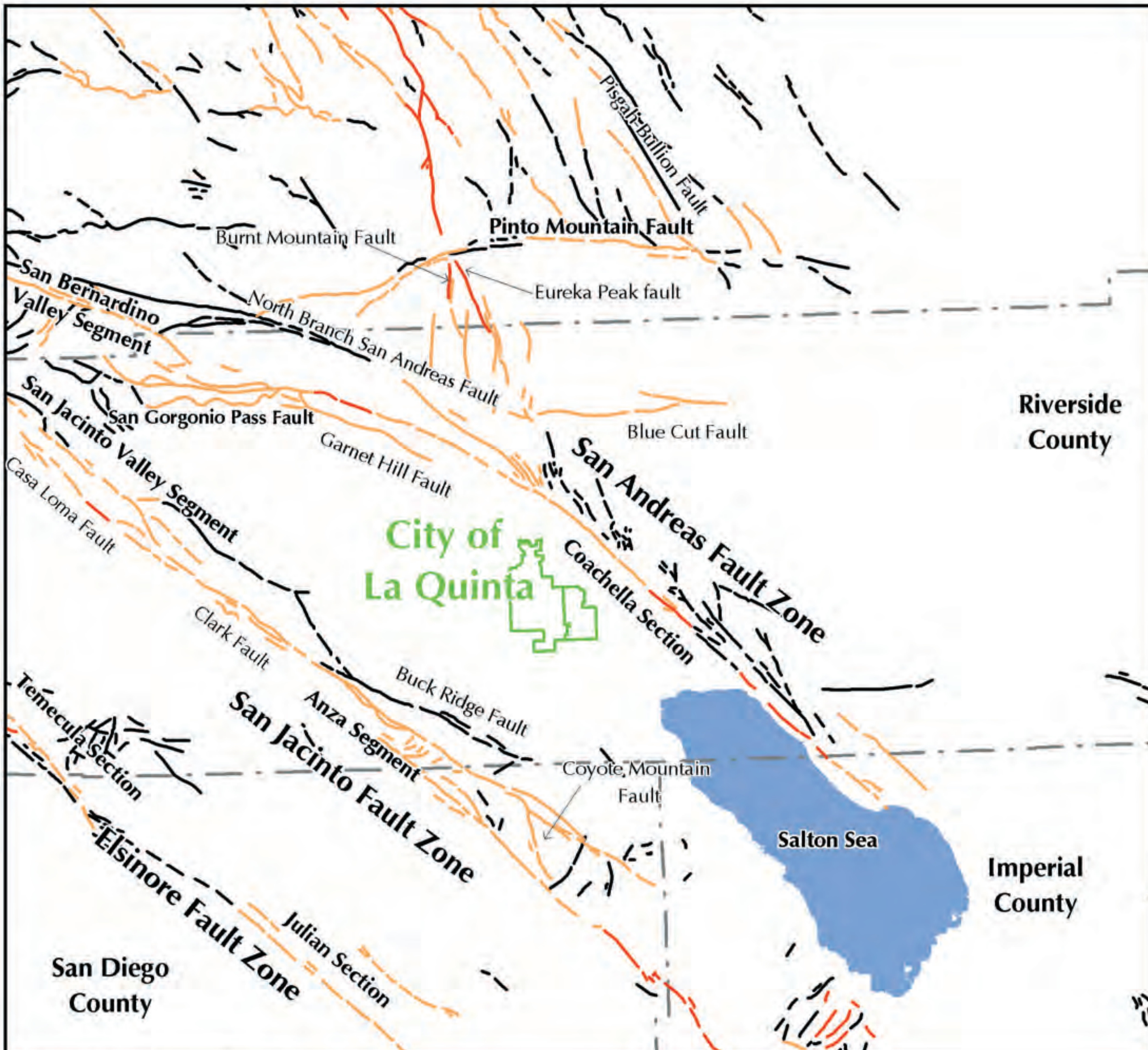
A smaller kink in the San Andreas fault occurs in the vicinity of San Gorgonio Pass, to the northwest of Palm Springs. This kink (or "knot" as it is often called) is a result of a slight bend and a step in the main fault's surface trace. As with the Big Bend, complex fault patterns, including thrust faulting, have developed in this area to accommodate these changes. Consequently, the Coachella Valley area, including the city of La Quinta, is exposed to risk from multiple types of earthquake-producing faults. The highest risks are due to movement on the San Andreas (strike-slip, right-lateral) fault zone (which includes the San Gorgonio Pass thrust fault), the San Jacinto (strike-slip, right-lateral) fault zone, the Pinto Mountain fault (strike slip, left-lateral), faults in the Eastern California Shear Zone (including the right-lateral strike-slip Burnt Mountain, Eureka Peak, and Pisgah-Bullion Mountain-Mesquite Lake faults), and the Elsinore fault (strike-slip, right-lateral). These faults or fault zones will be discussed in more detail in Section 1-4 below.

1.2 Regulatory Context

1.2.1 Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Special Studies Zones Act was signed into law in 1972 (in 1994 it was renamed the Alquist-Priolo Earthquake Fault Zoning Act). The primary purpose of the Act is to mitigate the hazard of fault rupture by prohibiting the location of structures for human occupancy across the trace of an active fault (Hart and Bryant, 1999; 2007). This State law was passed in direct response to the 1971 San Fernando earthquake, which was associated with extensive surface fault ruptures that damaged numerous homes, commercial buildings and other structures.

The Act requires the State Geologist (Chief of the California Geological Survey) to delineate "Earthquake Fault Zones" along faults that are "sufficiently active" and "well defined." These faults show evidence of Holocene (the time period between the present and about 11,000 years before present) surface displacement along one or more or their segments (sufficiently active) and are clearly detectable by a trained geologist as a physical feature at or just below the ground surface (well defined). The boundary of an "Earthquake Fault Zone" is generally about 500 feet from major active faults, and 200 to 300 feet from well-defined minor faults. Alquist-Priolo maps are distributed to all affected cities and counties for their use in planning and controlling new or renewed construction. The Act dictates that cities and counties withhold development permits for sites within an Earthquake Fault Zone until geologic investigations demonstrate that the sites are not threatened by surface displacements from future faulting (Hart and Bryant, 2007). Projects include all land divisions and most structures for human occupancy. State law exempts single-family wood-frame and steel-frame dwellings that are less than three stories and are not part of a development of four units or more. However, local agencies can be more restrictive. There are no Alquist-Priolo zoned faults in the La Quinta area. The closest zoned fault is the San Andreas fault to the north of the city (see Figure 1-2).



Modified from: Jennings, 1995

Explanation

- Fault Showing Evidence of Historic Rupture (Active).
- Fault Showing Evidence of Holocene Rupture (Active).
- Fault Showing Evidence of Quaternary and Late Quaternary Rupture (Potentially Active).

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Local Active and Potentially Active Faults

Figure 1-2

1.2.2 Seismic Hazards Mapping Act

The Alquist-Priolo Earthquake Fault Zoning Act only addresses the hazard of surface fault rupture and is not directed toward other earthquake hazards. Recognizing this, in 1990, the State passed the Seismic Hazards Mapping Act (SHMA), which addresses non-surface fault rupture earthquake hazards, including strong ground shaking, liquefaction and seismically induced landslides. The California Geological Survey (CGS) is the principal State agency charged with implementing the Act. Pursuant to the SHMA, the CGS is directed to provide local governments with seismic hazard zone maps that identify areas susceptible to liquefaction, earthquake-induced landslides and other ground failures. The goal is to minimize loss of life and property by identifying and mitigating seismic hazards. The seismic hazard zones delineated by the CGS are referred to as "zones of required investigation." Site-specific geological hazard investigations are required by the SHMA when construction projects fall within these areas.

The CGS, pursuant to the 1990 SHMA, has been releasing seismic hazards maps since 1997, with emphasis on the large metropolitan areas of Los Angeles, Orange and Ventura counties (funding for this program limits the geographic scope of this studies to these three counties in southern California). As a result, at this time, there are no State-issued (and therefore official) seismic hazard zone maps for the city of La Quinta. Nevertheless, the methodology that the CGS uses to prepare these maps is well documented, and can be duplicated in areas that the CGS has yet to map. To that end, and for the purposes of this study, we have followed a simplified version of the CGS methodology to identify areas in La Quinta that are susceptible to liquefaction or earthquake-induced slope instability. These hazards are discussed in more detail in Section 1.6.

1.2.3 California Building Code

The International Conference of Building Officials (ICBO) was formed in 1922 to develop a uniform set of building regulations; this led to the publication of the first Uniform Building Code (UBC) in 1927. In keeping with the intent of providing a safe building environment, building codes were updated on a fairly regular basis, but adoption of these updates at the county- and city-level was not mandatory. As a result, the building codes used from one community to the next were often not the same. Then in 1980, recognizing that many building code provisions, like exiting from a building, are not affected by local conditions, and to facilitate the concept that industries working in California should have some uniformity in building code provisions throughout the State, the legislature amended the State's Health and Safety Code to require local jurisdictions to adopt, at a minimum, the latest edition of the Uniform Building Code (UBC). The law states that every local agency, such as individual cities and counties, enforcing building regulations must adopt the provisions of the California Building Code (CBC) within 180 days of its publication; although each jurisdiction can require more stringent regulations, issued as amendments to the CBC. The publication date of the CBC is established by the California Building Standards Commission and the code is known as Title 24 of the California Code of Regulations. Based on the publication cycle of the UBC, the CBC used to be updated and republished every three years.

Then, in 1994, to further the concept of uniformity in building design, the ICBO joined with the two other national building code publishers, the Building Officials and Code Administrators International, Inc. (BOCA) and the Southern Building Code Congress International, Inc. (SBCCI), to form a single organization, the International Code Council, (ICC). In the year 2000, the group published the first International Building Code (IBC) as well as an entire family of codes, (i.e. building, mechanical, plumbing and fire) that were coordinated with each other. As a result, the last (and final) version of the UBC was issued in 1997. After the formation of the ICC and the publication of the IBC, the California legislature did not address the matter of updating the CBC with a building code other than the UBC. In fact, the California Building Standards Commission, after careful review of the 2000 IBC, chose not to use the IBC, but instead continued to adopt the older 1997 UBC as the basis for the CBC. The 2001 CBC (based on the 1997 UBC) was used throughout the State from 2001 to 2007, often with local, more restrictive amendments based upon local geographic, topographic or climatic conditions.

In 2003, California considered adopting the National Fire Protection Association (NFPA) 5000 building code. Specifically, on July 29, 2003, the California Building Standards Commission recommended adoption of the NFPA 5000 code as the basis for California's next building code. However, state agencies that reviewed the proposed building code found it to be incomplete, requiring the adoption of substantial amendments, many transcribed directly from the CBC, to bring it to the level provided by the 2001 CBC. For this and other reasons, including the cost of developing the amendments and training state, county and city officials responsible for the enforcement of the code, on March 8, 2005, the Coordinating Council of the California Building Standards Commission recommended rescission of the 2003 decision to adopt the NFPA 5000 code, and instead recommended adoption of the latest International Building Code (IBC) as the basis for the next CBC. Thus, the California Building Standards Commission (BSC) reviewed the 2006 IBC, and using the IBC as a basis, prepared the 2007 edition of the CBC. The building code in use as of the writing of this document became available to the public on July 1, 2007, and became effective on January 1, 2008. However, the 2010 California Building Standards Code based on the 2009 International Building Code is expected to become effective on January 1, 2011. [For more recent information regarding this subject, refer to the California Building Standards Commission website at www.bsc.ca.gov/].

It is emphasized that building codes provide **minimum** requirements. With respect to seismic shaking, for example, the provisions of the building code are designed to prevent the catastrophic collapse of structures during a strong earthquake; however, structural damage to buildings, and potential loss of functionality, are expected. Specific provisions contained in the California Building Code that pertain to seismic and geologic hazards are discussed further in other sections of this document.

1.2.4 Unreinforced Masonry Law

Enacted in 1986, the Unreinforced Masonry Law (Senate Bill 547, codified in Section 8875 et seq. of the California Government Code) required all cities and counties in zones near historically active faults (Seismic Zone 4 per the Building Code at the time of the bill passage) to identify potentially hazardous unreinforced masonry (URM) buildings in their jurisdictions, establish an URM loss-reduction program, and report their progress to the State by 1990. The owners of such buildings were to be notified of the potential earthquake hazard these buildings pose. Some jurisdictions implemented mandatory retrofit programs, while others established voluntary programs. A few cities only notified the building owners, but did not adopt any type of strengthening program. Starting in 1997, California required all jurisdictions to enforce the 1997 Uniform Code for Building Conservation (UCBC) Appendix Chapter 1 as the model building code, although local governments could adopt amendments to that code under certain circumstances (ICBO, 2001; CSSC, 2006). The UCBC standards are meant to significantly reduce but not necessarily eliminate the risk to life from collapse of the structure. Prior to 1997, local governments could adopt other building standards that preceded the UCBC, and in fact, in many jurisdictions, retrofits were conducted in accordance with local ordinances that only partially complied with the latest UCBC. The 2007 California Building Code (CBC) includes newly approved building standards for historical buildings (2007 California Historical Building Code, Part 8 of Title 24), and building standards for existing buildings (2007 California Existing Building Code, Part 10 of Title 24) based on the 2006 International Existing Building Code.

In 2006, the City of La Quinta reported to the Seismic Safety Commission that there were seven historic URMs in the city. Five of these had been strengthened and were in compliance with the City's mandatory mitigation program; one was slated for demolition; and one had not been mitigated or shown mitigation progress. In 2010, personnel from the La Quinta Building Department have indicated that these two URMs, which are adobe structures, are still unmitigated, but vacant and not being used. Both are located on the grounds of the La Quinta Resort.

1.2.5 Real Estate Disclosure Requirements

Since June 1, 1998, the Natural Hazards Disclosure Act has required that sellers of real property and their agents provide prospective buyers with a "Natural Hazard Disclosure Statement" when the property being sold lies within one or more State-mapped hazard areas. For example, if a property is located in a Seismic Hazard Zone as shown on a map issued by the State Geologist, the seller or the seller's agent must disclose this fact to potential buyers. The law specifies two ways in which this disclosure can be made: (1) Using the Natural Hazards Disclosure Statement as provided in Section 1102.6c of the California Civil Code, or (2) using the Local Option Real Estate Disclosure Statement as provided in Section 1102.6a of the California Civil Code. The Local Option Real Estate Disclosure Statement (Option 2) can be substituted for the Natural Hazards Disclosure Statement (Option 1) only if the Local Option Statement contains substantially the same information and substantially the same warnings as the Natural Hazards Disclosure Statement.

California State law also states that when houses built before 1960 are sold, the seller must give the buyer a completed earthquake hazards disclosure report and a copy of the booklet entitled "The Homeowner's Guide to Earthquake Safety." This publication was written and adopted by the California Seismic Safety Commission. The most recent edition of this booklet is available from the web at www.seismic.ca.gov/. The booklet includes a sample of a residential earthquake hazards report that buyers are required to fill in, and describes structural weaknesses common in homes that if they fail in an earthquake can result in significant damage to the structure. The booklet then provides detailed information on actions that homeowners can take to strengthen their homes.

Those regions in the study area that have the potential of being impacted by seismically induced liquefaction or slope instability (see Section 1.6), as identified in this report, should be disclosed to prospective buyers, following the provisions of the Natural Hazards Disclosure Act.

1.2.6 California Environmental Quality Act

The California Environmental Quality Act (CEQA) was passed in 1970 to insure that local governmental agencies consider and review the environmental impacts of development projects within their jurisdictions. CEQA requires that an Environmental Impact Report (EIR) be prepared for projects that may have significant effects on the environment. EIRs are required to identify geologic and seismic hazards, and to recommend potential mitigation measures, thus giving the local agency the authority to regulate private development projects in the early stages of planning. The law requires that these documents be issued in draft form and made available at local libraries and City Hall for individuals and organizations to review and comment on. The comments are addressed in the final report submitted for approval or refusal by the Planning Commission and/or City Council.

1.3 Notable Past Earthquakes

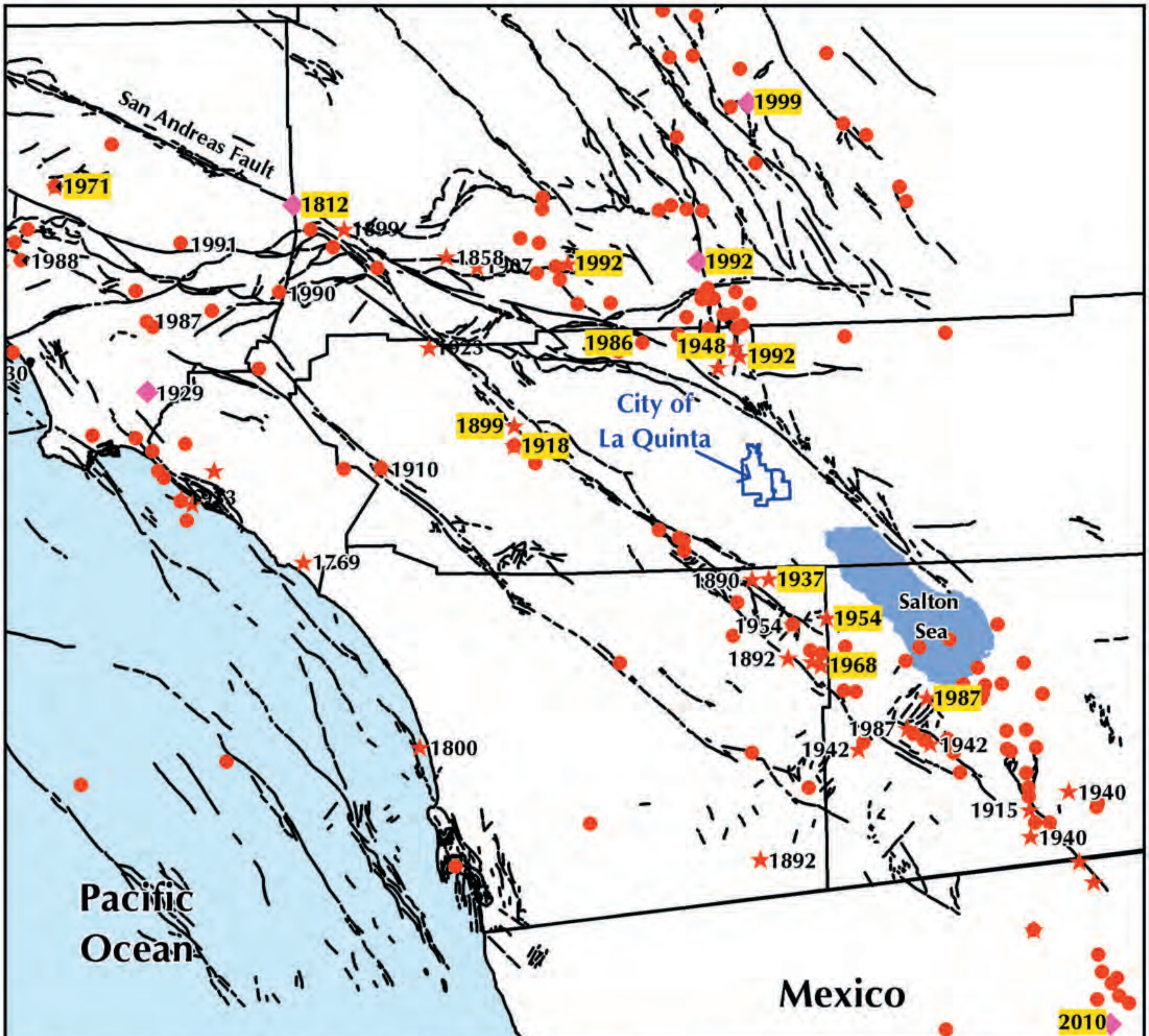
Figure 1-3 shows the approximate epicenters of some of the historical earthquakes that have resulted in significant ground shaking in the southern California area, including La Quinta. The most significant of these events, either because they were felt strongly in the area, or because they led to the passage of important legislation, are described below.

1.3.1 Wrightwood Earthquake of December 12, 1812

This large earthquake occurred on December 8, 1812 and was felt throughout southern California. Based on accounts of damage recorded at missions in the earthquake-affected area, an estimated magnitude of 7.5 has been calculated for the event (Toppozada et al., 1981). Subsurface investigations and tree ring studies show that the earthquake likely ruptured the Mojave Section of the San Andreas fault near Wrightwood, and may have been accompanied by a significant surface rupture between Cajon Pass and Tejon Pass (Jacoby, Sheppard and Sieh, 1988; www.scecdc.scec.org/quakedex.html). The worst damage caused by the earthquake occurred significantly west of the San Andreas fault at San Juan Capistrano Mission, where the roof of the church collapsed, killing 40 people. The earthquake also damaged walls and destroyed statues at San Gabriel Mission, and is thought to have triggered an earthquake thirteen days later that damaged several missions in the Santa Barbara area (Deng and Sykes, 1996). Strong aftershocks that occurred for several days after the main earthquake collapsed many buildings that had been damaged by the main shock.

1.3.2 San Jacinto Earthquake of 1899

This earthquake occurred at 4:25 in the morning on Christmas Day, in 1899. The main shock is estimated to have had a magnitude of 6.5. Several smaller aftershocks followed the main shock, and in the town of San Jacinto, as many as thirty smaller tremors were felt throughout the day. The epicenter of this earthquake is not well located, but damage patterns suggest the location shown on Figure 1-3, near the town of San Jacinto, with the causative fault most likely being the San Jacinto fault. Both the towns of San Jacinto and Hemet reported extensive damage, with nearly all brick buildings either badly damaged or destroyed. Six people were killed in the Soboba Indian Reservation as a result of falling adobe walls. In Riverside, chimneys toppled and walls cracked (Claypole, 1900). The main earthquake was felt over a broad area that included San Diego to the southwest, Needles to the northeast, and Arizona to the east. No surface rupture was reported, but



Source: Jennings, 1994; SCEC earthquake catalog; NEIC earthquake catalog

N
W E
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Explanation

◆	Magnitude 7+	—	Quaternary faults
★	Magnitude 6 - 7	1899	Earthquakes discussed further in the text
●	Magnitude 5 - 6		

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Date: 2010

Notable Regional Earthquakes

Figure 1-3

several large "sinks" or subsidence areas were reported about 10 miles to the southeast of San Jacinto.

1.3.3 San Jacinto Earthquake of 1918

This magnitude 6.8 earthquake occurred on April 21, 1918 at 2:32 P.M. Pacific Standard Time (PST), near the town of San Jacinto. The earthquake caused extensive damage to the business districts of San Jacinto and Hemet, where many masonry structures collapsed, but because it occurred on a Sunday, when these businesses were closed, the number of fatalities and injuries was low. Several people were injured, but only one death was reported. Minor damage as a result of this earthquake was reported outside the San Jacinto area, and the earthquake was felt as far away as Taft (west of Bakersfield), Seligman (Arizona), and Baja California.

Strong shaking cracked the ground, concrete roads, and concrete irrigating canals, but none of the cracks are thought to have been caused directly by surface fault rupture. The shaking also triggered several landslides in mountain areas. The road from Hemet to Idyllwild was blocked in several places where huge boulders rolled down slopes. Two men in an automobile were reportedly swept off a road by a landslide, and would have rolled several hundred feet down a hillside had they not been stopped by a large tree. Two miners were trapped in a mine near Winchester, but they were eventually rescued, uninjured. The earthquake apparently caused changes in the flow rates and temperatures of several springs. Sand craters (due most likely to liquefaction) were reported on one farm, and an area near Blackburn Ranch "sunk" approximately three feet (one meter) during the quake (/www.scecdc.scec.org/quakedex.html).

1.3.4 San Jacinto Fault Earthquake of 1937

This magnitude 6.0 earthquake occurred on March 25, 1937 at 8:49 AM PST, just after the advent of modern seismology, and as a result, it is one of the first earthquakes for which both an epicentral location and numerical magnitude value (using the newly developed Richter scale) were determined. The event is known as the Terwilliger Valley earthquake, although this is actually a misnomer, since its epicenter is almost 19 miles (30 km) to the east-southeast of Terwilleger Valley. The earthquake caused very little damage given that the epicentral area was (and still is) sparsely populated. Nevertheless, a few chimneys were toppled, plaster cracked, and windows broke in structures located relatively near the epicenter (Wood, 1937). "It was recognized at the time, however, that the quake could have easily caused the kind of damage seen in Santa Barbara in 1925 or in Long Beach in 1933, had it been located in a densely populated area, being nearly the same magnitude as those destructive quakes" (http://www.data.scec.org/chrono_index/sanj37.html).

1.3.5 Desert Hot Springs Earthquake of 1948

This magnitude 6.0 earthquake struck on December 4, 1948 at 3:43 P.M. PST. The fault involved is believed to be the South Branch of the San Andreas (or Banning fault, depending on nomenclature used). The Desert Hot Springs earthquake of 1948 not only was felt over a large area (as far away as central Arizona, parts of Mexico, Santa Catalina Island, and Bakersfield), but also caused notable damage in regions far from the epicenter. In the Los Angeles area, a 5,800-gallon water tank split open, water pipes were broken at UCLA and in Pasadena, and plaster cracked and fell from many buildings. In San Diego, a water main broke. In Escondido and Corona, walls were cracked. The administration building of Elsinore High School was permanently closed, due to the damage it sustained, as was a building at the Emory School in Palm City. Closer to the epicenter, landslides and ground cracks were reported, and a road leading to the Morongo Indian Reservation was badly damaged (Louderback, 1949). In Palm Springs, the city hit hardest by the quake, thousands of dollars of merchandise was thrown from shelves and destroyed. Part of a furniture store collapsed. Two people were injured when the shaking induced a crowd to flee a movie theater in panic. Numerous other instances of minor structural damage were reported. Fortunately, despite the damage brought on by this earthquake, no lives were lost.

1.3.6 San Jacinto Fault Earthquake of 1954

This magnitude 6.4 earthquake struck on March 19, 1954 at 1:54 A.M. PST. Magistrale and others (1989) suggest that the Clark fault of the San Jacinto fault zone was involved. The 1954 San Jacinto fault earthquake, sometimes referred to as the Arroyo Salada earthquake, caused minor damage over a wide area of southern California, cracking plaster walls as far away as San Diego, and knocking plaster from the ceiling at the Los Angeles City Hall. In Palm Springs, a water pipe was broken, and the walls of several swimming pools were cracked. Part of San Bernardino experienced a temporary blackout when power lines snapped in the shaking. Indio and Coachella also experienced minor damage. The shock was felt as far away as Ventura County, Baja California, and Las Vegas (Louderback, 1954).

1.3.7 Borrego Mountain Earthquake of 1968

This magnitude 6.5 earthquake struck on April 8, 1968 at 6:29 P.M. It resulted in about 18 miles of surface rupture along the Coyote Creek fault (a branch of the San Jacinto Fault Zone), and triggered slip was observed on fault systems up to 40 miles away. When the Borrego Mountain earthquake struck, it was the largest and most damaging quake to hit southern California since the Kern County earthquake of 1952. It was felt as far away as Las Vegas, Fresno, and even Yosemite Valley. The quake caused damage across most of southern California – power lines were severed in San Diego County, plaster cracked in Los Angeles, and the Queen Mary, in dry-dock at Long Beach, rocked back and forth on its keel blocks for 5 minutes. A few ceilings collapsed at various places in the Imperial Valley. Close to the epicenter, the quake caused landslides, hurling large boulders downslope, damaging campers' vehicles at Anza-Borrego Desert State Park, and caused minor surface rupture, cracking Highway 78 at Ocotillo Wells (Lander, 1968).

The event apparently caused small displacements along the Superstition Hills fault (2.2 cm), Imperial fault (1.2 cm), and the Banning-Mission Creek fault (0.9 cm), 45 km, 70 km, and 50 km, respectively, from the epicenter. These fresh breaks and displacements were not noticed immediately after the mainshock, but no other significant events occurred within the interim that could have caused them. These are probably among the first noted instances of triggered slip, and they proved to be some of the most intriguing features of the Borrego Mountain earthquake.

1.3.8 San Fernando (Sylmar) Earthquake of 1971

This magnitude 6.6 earthquake occurred on the San Fernando fault zone, the westernmost segment of the Sierra Madre fault, on February 9, 1971, at 6:00 A.M. The surface rupture caused by this earthquake was nearly 12 miles long, and occurred in the Sylmar-San Fernando area. The maximum slip measured at the surface was nearly six feet. The earthquake caused over $500 million in property damage and 65 deaths. Most of the deaths occurred when the Veteran's Administration Hospital collapsed. Several other hospitals, including the Olive View Community Hospital in Sylmar suffered severe damage. Newly constructed freeway overpasses also collapsed, in damage scenes similar to those that occurred 23 years later in the 1994 Northridge earthquake. Loss of life could have been much greater had the earthquake struck at the busier time of the day. As with the Long Beach earthquake, legislation was passed in response to the damage caused by the 1971 earthquake. In this case, the building codes were strengthened and the Alquist-Priolo Special Studies (now call the Earthquake Fault Zone) Act was passed in 1972.

1.3.9 North Palm Springs Earthquake of 1986

This magnitude 5.6 earthquake occurred on July 8, 1986 at 2:21 A.M. PDT, along either the Banning fault or the Garnet Hill fault. The epicenter was about 6 miles northwest of Palm Springs, and about 28 miles from La Quinta. The North Palm Springs earthquake was responsible for at least 29 injuries and the destruction or damage of 51 homes in the Palm Springs-Morongo Valley area. It also triggered landslides in the region. Damage caused by this quake was estimated at over $4 million. Ground cracking was observed along the Banning, Mission Creek, and Garnet Hill faults, but these cracks were due to shaking, not surface rupture (Person, 1986). Most of the ground fractures occurred on the northern side of the fault, between Whitewater Canyon on the west, and Highway 62 on the east. Fractures varied from single, discontinuous breaks less than 1 mm wide, to extensively fractured zones 30 to 40 m (100 to 120 feet) wide (Morton et al., 1989).

1.3.10 Elmore Ranch and Superstition Hills Earthquakes of 1987

The magnitude 6.2 Elmore Ranch earthquake struck on November 23, 1987 at 5:54 P.M. PST. This earthquake resulted in left-lateral strike-slip motion along the Elmore Ranch and associated faults, and appears to have triggered a larger earthquake the next morning on the right-lateral Superstition Hills fault, which is perpendicular to the Elmore Ranch systems (Hudnut and others, 1989). A maximum surface offset of 12.5 centimeters was reported, and the faults where surface rupture was observed included the Elmore Ranch (main, west, and east branches), Lone Tree, and Kane Spring (main and east branches). The magnitude 6.6 Superstition Hills earthquake occurred the morning of November 24, at 6:16 A.M. PST, near the Salton Sea. A maximum surface offset of about 20 inches was observed on the Superstition Hills fault within 24 hours of the earthquake. However, during the next several months, the offset was observed to have increased to about three feet, and triggered slip was observed on the Imperial, San Andreas, and Coyote Creek faults (Sharp et al., 1989).

1.3.11 Joshua Tree Earthquake of 1992

This magnitude 6.1 earthquake struck on April 22, 1992 at 9:50 P.M. PST, approximately 20 miles north of La Quinta. This event resulted from right-lateral strike-slip faulting and was preceded by a magnitude 4.6 foreshock. The Joshua Tree earthquake raised some alarms due to its proximity to the San Andreas fault. A San Andreas Hazard Level B was declared following this quake, meaning that the San Andreas fault was given a 5% to 25% chance of generating an even larger earthquake within three days. Roughly two months and 6,000 aftershocks later, the Landers earthquake broke the surface of the Mojave Desert in the largest quake to hit southern California in 40 years, showing that the concern caused by the Joshua Tree earthquake was at least partially warranted. The aftershocks of the Joshua Tree quake suggested that the fault that slipped is a north-northwest-trending, right-lateral strike-slip fault at least 15 km long (Jones et al., 1995). Based on these data, and the location of the shocks, researchers suggest that the Eureka Peak fault may have been the fault responsible for this earthquake.

Damage caused by the Joshua Tree earthquake was slight to moderate in the communities of Joshua Tree, Yucca Valley, Desert Hot Springs, Palm Springs, and Twentynine Palms. Thirty-two people had to be treated for minor injuries. Though somewhat forgotten in the wake of the Landers earthquake, the Joshua Tree quake was a significant event on its own, and was felt as far away as San Diego, Santa Barbara, Las Vegas, Nevada, and even Phoenix, Arizona (Person, 1992).

1.3.12 Landers Earthquake of 1992

On the morning of June 28, 1992, most people in southern California were awakened at 4:57 by the largest earthquake to strike California in 40 years. Named "Landers" after the small desert community near its epicenter, the earthquake had a magnitude of 7.3. More than 50 miles of surface rupture associated with five or more faults occurred as a result of this earthquake. The average right-lateral strike-slip displacement was about 10 to 15 feet, but a maximum of up to 18 feet was observed. Centered in the Mojave Desert approximately 120 miles from Los Angeles, the earthquake caused relatively little damage for its size (Brewer, 1992). It released about four times as much energy as the very destructive Loma Prieta earthquake of 1989, but fortunately, it did not claim as many lives (one child died when a chimney collapsed). The power of the earthquake was illustrated by the length of the ground rupture it left behind. The earthquake ruptured five separate faults: Johnson Valley, Landers, Homestead Valley, Emerson, and Camp Rock faults (Sieh et al., 1993). Other nearby faults also experienced triggered slip and minor surface rupture.

1.3.13 Big Bear Earthquake of 1992

This magnitude 6.4 earthquake struck little more than 3 hours after the Landers earthquake on June 28, 1992 at 8:05:30 A.M. PDT. This earthquake is technically considered an aftershock of the Landers earthquake (indeed, the largest aftershock), although the Big Bear earthquake occurred over 20 miles west of the Landers rupture, on a fault with a different orientation and sense of slip than those involved in the main shock. From its aftershocks, the causative fault was determined to be a northeast-trending left-lateral fault. This orientation and slip are considered "conjugate" to the faults that slipped in the Landers rupture. The Big Bear earthquake did not break the ground surface, and, in fact, no surface trace of a fault with the proper orientation has been found in the area.

The Big Bear earthquake caused a substantial amount of damage in the Big Bear area, but fortunately, it claimed no lives. However, landslides triggered by the quake blocked roads in that mountainous area, aggravating the clean-up and rebuilding process (www.scecdc.scec.org/quakedex.html).

1.3.14 Hector Mine Earthquake of 1999

Southern California's most recent large earthquake was a widely felt magnitude 7.1. It occurred on October 18, 1999, in a remote region of the Mojave Desert, 47 miles east-southeast of Barstow. Modified Mercalli Intensities of V (Table 1-1) were reported in the La Quinta area (http://earthquake.usgs.gov/earthquakes/dyfi/events/ci/hectormi/us/index.html). The Hector Mine earthquake is not considered an aftershock of the M 7.3 Landers earthquake of 1992, although Hector Mine occurred on similar, north-northwest trending strike-slip faults within the Eastern Mojave Shear Zone. Geologists documented a 25-mile (40-km) long surface rupture and a maximum right-lateral strike-slip offset of about 16 feet on the Lavic Lake fault.

1.3.15 Baja California Earthquake of 2010

A magnitude 7.2 earthquake that occurred just south of the U.S. / Mexico border on Easter Sunday, April 4, 2010, at 3:40:42 PM PDT, was felt throughout Mexico, southern California, Arizona, and Nevada. Researchers are still reviewing the data, but preliminary analysis suggests that there were two sub-events, with the first one rupturing an 18-km section of the Pescadores fault, followed, six to 12 seconds later by a second, larger event on the Borrego fault. Both of these faults are part of the Laguna Salada fault system, which is the southern extension of the Elsinore fault. Surface rupture continued northward to just past the border into California. The main earthquake caused triggered slip of up to a few centimeters on several faults in the Salton Sea area, and as far north as in the Mecca Hills. Secondary effects, including liquefaction, rockfalls and shattering were reported along a wide area in the El Centro and Brawley region, and westward toward San Diego. A peak instrumental ground acceleration of 1.1g was recorded at the Salton Sea. Similar or stronger shaking may have occurred closer to the epicenter, but given the lack of instrumentation in that area, went unrecorded. Based on observations reported by many residents, shaking in La Quinta as a result of this earthquake was light, in the Modified Mercalli intensity IV range (http://earthquake.usgs.gov/earthquakes/dyfi/events/ci/14607652/us/index.html). Ten days after the main shock, more than 4,000 aftershocks had been recorded (http://www.scsn.org/2010sierraelmayor.html). Many of the aftershocks occurred along the Elsinore, San Jacinto, and the southern extension of the San Andreas fault through the Brawley area. The largest aftershock to date was a magnitude 5.7 on June 14, 2010 that occurred just north of the International Border, about 5 miles from Ocotillo.

1.4 Seismic Ground Shaking

Strong ground shaking causes the vast majority of earthquake damage. As mentioned previously, when a fault breaks in the subsurface, the seismic energy released by the earthquake radiates away from the hypocenter in waves that are felt at the surface as shaking. In general, the bigger and closer the earthquake, the more damage it may cause. However, other effects discussed below are also important. Earthquakes are typically classified by the amount of damage reported, or by how strong and how far the shaking was felt. An early measure of earthquake size still used today is the seismic intensity scale, which is a qualitative assessment of an earthquake's effects at a given location. The most commonly used measure of seismic intensity is called the ***Modified Mercalli Intensity*** (MMI) scale, which has 12 damage levels (see Table 1-1). Although it has limited scientific application, intensity is intuitively clear and quick to determine. Keep in mind, however, that earthquake damage depends on the characteristics of human-made structures, and the complex interaction between the ground motions and the built environment. Governing factors include a building's height, construction, and stiffness, which determine the structure's resonant period; the underlying soil's strength and resonant period; and the periods of the incoming seismic waves. Other factors include architectural design, condition, and age of the structures.

Table 1-1: Abridged Modified Mercalli Intensity Scale

Intensity Value and Description		Average Peak Velocity (cm/sec)	Average Peak Acceleration (g = gravity)
I.	Not felt except by very few under especially favorable circumstances (I Rossi-Forel scale). Damage potential: None.	<0.1	<0.0017
II.	Felt only by a few persons at rest, especially on upper floors of high-rise buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale). Damage potential: None.	0.1 – 1.1	0.0017 – 0.014
III.	Felt quite noticeably indoors, especially on upper floors of buildings, but many people did not recognize it as an earthquake. Standing automobiles may have rocked slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale). Damage potential: None.		
IV.	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made creaking sound. Sensation like a heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale). Damage potential: None. Perceived shaking: Light.	1.1 – 3.4	0.014 - 0.039
V.	Felt by nearly everyone; many awakened. Some dishes, windows, and so on broken; plaster cracked in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may have stopped. (V to VI Rossi-Forel scale). Damage potential: Very light. Perceived shaking: Moderate.	3.4 – 8.1	0.039-0.092
VI.	Felt by all; many frightened and ran outdoors. Some heavy furniture moved, few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale). Damage potential: Light. Perceived shaking: Strong.	8.1 - 16	0.092 -0.18
VII.	Everybody ran outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel scale). Damage potential: Moderate. Perceived shaking: Very strong.	16 - 31	0.18 - 0.34
VIII.	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII+ to IX Rossi-Forel scale). Damage potential: Moderate to heavy. Perceived shaking: Severe.	31 - 60	0.34 - 0.65
IX.	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel scale). Damage potential: Heavy. Perceived shaking: Violent.	60 - 116	0.65 – 1.24
X.	Some well-built wooden structures destroyed; most masonry and frame structures destroyed; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel scale). Damage potential: Very heavy. Perceived shaking: Extreme.	> 116	> 1.24
XI.	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.		
XII.	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into air.		

Modified from Bolt (1999); Wald and others (1999).

Scientists used to measure the amplitude of ground motion, as recorded by an instrument a given distance from the epicenter, to report the size of an earthquake (such as the now outdated Richter magnitude). Seismologists now find that the most meaningful factor in determining the size of an earthquake is the amount of energy released when a fault ruptures. This measure is called the ***seismic moment*** (abbreviated M_w), and most moderate to large earthquakes today are reported using moment magnitude. Both traditional magnitude scales and seismic moment scales are logarithmic. Thus, each one-point increase in magnitude represents a ten-fold increase in amplitude of the waves as measured at a specific location, and a 32-fold increase in energy. That is, a Richter magnitude 7 earthquake produces 100 times (10 x 10) the ground motion amplitude of a magnitude 5 earthquake. Similarly, a moment magnitude 7 earthquake releases approximately 1,000 times more energy (32 x 32) than a moment magnitude 5 earthquake.

An important point to remember is that any given earthquake will have one moment and, in principle, one magnitude, although there are several methods of calculating magnitude, which give slightly different results. However, one earthquake will produce many levels of intensity because intensity effects vary with the location and the perceptions of the observer.

Fault dimensions and proximity are key parameters in any hazard assessment. In addition, it is important to know a fault's style of movement (i.e., is it dip-slip or strike-slip), total displacement, slip rate, and the age of its most recent activity. These values allow an estimation of how often a fault produces damaging earthquakes, and how big an earthquake should be expected the next time the fault ruptures. Horizontal ground acceleration is frequently responsible for widespread damage to structures, so it is commonly estimated as a percentage of ***g***, the ***acceleration of gravity***. Full characterization of shaking potential, though, requires estimates of peak (maximum) ground displacement and velocity, the duration of strong shaking, and the periods (lengths) of waves that will control each of these factors at a given location.

In general, the degree of shaking can depend upon:

- **Source effects**. These include earthquake size, location, and distance. In addition, the exact way that rocks move along the fault can influence shaking. For example, the 1995, M_W 6.9 Kobe, Japan earthquake was not much bigger than the 1994, M_W 6.7 Northridge, California earthquake, but the city of Kobe suffered much worse damage. This is in part because during the Kobe earthquake, the fault's orientation and movement directed seismic waves into the city, whereas during the Northridge earthquake, the fault's motion directed waves away from populous areas.

- **Path effects**. Seismic waves change direction as they travel through the Earth's contrasting layers, just as light bounces (reflects) and bends (refracts) as it moves from air to water. Sometimes seismic energy gets focused in one location and causes damage in unexpected areas. Focusing of the seismic waves during the 1989 M_W 7.1 Loma Prieta earthquake caused damage in San Francisco's Marina district, some 62 miles (100 km) distant from the rupturing fault.

- **Site effects**. Seismic waves slow down in the loose sediments and weathered rock at the Earth's surface. As they slow, their energy converts from speed to amplitude, which heightens shaking. This is similar to the behavior of ocean waves – as the waves slow down near shore, their crests grow higher. The Marina District of San Francisco also serves as an example of site effects. Earthquake motions were greatly amplified in the deep, sediment-filled basin underlying the District compared to the surrounding bedrock areas. Seismic waves can get trapped at the surface and reverberate (resonate). Whether resonance will occur depends on the period (the length) of the incoming waves. Waves, soils and buildings all have resonant periods. When these coincide, tremendous damage can occur.

[Waves repeat their motions with varying frequencies. Slow-to-repeat waves are called long-period waves. Quick-to-repeat waves are called short-period waves. Long-period seismic waves, which are created by large earthquakes, are most likely to reverberate and cause damage in long-period structures, like bridges and high-rise buildings that respond to long-period waves. Shorter-period seismic waves, which tend to die out quickly, will most often cause damage in areas relatively close to the rupturing fault, and they will cause most damage to shorter-period structures such as one- to three-story buildings. Very short-period waves are most likely to cause near-fault, interior damage, such as to equipment.]

Seismic shaking has the potential to impact the La Quinta area, given that the city is located just south of the most significant seismic source (fault) in southern California, the San Andreas fault, and not too far from another significant fault, the San Jacinto. Both of these faults have the potential to generate large to moderate earthquakes that would be felt in the La Quinta area.

Plate 1-1 shows the epicentral locations of earthquakes in and around the city that were instrumentally detected between 1932 and April 2010, and those estimated to have occurred in the area between about 1800 and 1932. Earthquakes that occurred prior to 1932 are only approximately located because prior to that year there were no instruments available to measure the location and magnitude of an earthquake. The map shows that only a few magnitude 4 and smaller earthquakes have occurred in the La Quinta General Plan area proper. Significant seismicity occurs to the north, along the San Andreas fault zone, and to a lesser extent to the south, under the San Jacinto Mountains, most likely associated with the San Jacinto fault.

In order to provide a better understanding of the shaking hazard posed by those faults near the General Plan area, we conducted a deterministic seismic hazard analysis for a central point in the city (City Hall) and several other randomly selected points in the General Plan area using the software program EQFAULT by Blake (2000). This analysis estimates the Peak Horizontal Ground Accelerations (PHGA) that could be expected at these locations due to earthquakes occurring on any of the known active or potentially active faults within about 62 miles (100 km). The fault database (including fault locations and earthquake magnitudes of the maximum magnitude earthquakes for each fault) used to conduct these seismic shaking analyses is that used by the California Geological Survey (CGS) and the U.S. Geological Survey (USGS) for the National Seismic Hazard Maps (Petersen and others, 1996; Cao and others, 2003). However, as described further in the text, recent paleoseismic studies suggest that some of these faults may actually generate even larger earthquakes than those used in the analysis. Where appropriate, this is discussed further below.

PGHA depends on the size of the earthquake, the proximity of the rupturing fault, and local soil conditions. Effects of soil conditions are estimated by use of an attenuation relationship derived empirically from an analysis of recordings of earthquake shaking in similar soils during earthquakes of various sizes and distances. Given that most of the developed portions of La Quinta are underlain by alluvial sediments, we used alluvium for most of the deterministic analyses conducted for this study, and the attenuation relationships of Campbell and Bozorgnia (1997,

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.

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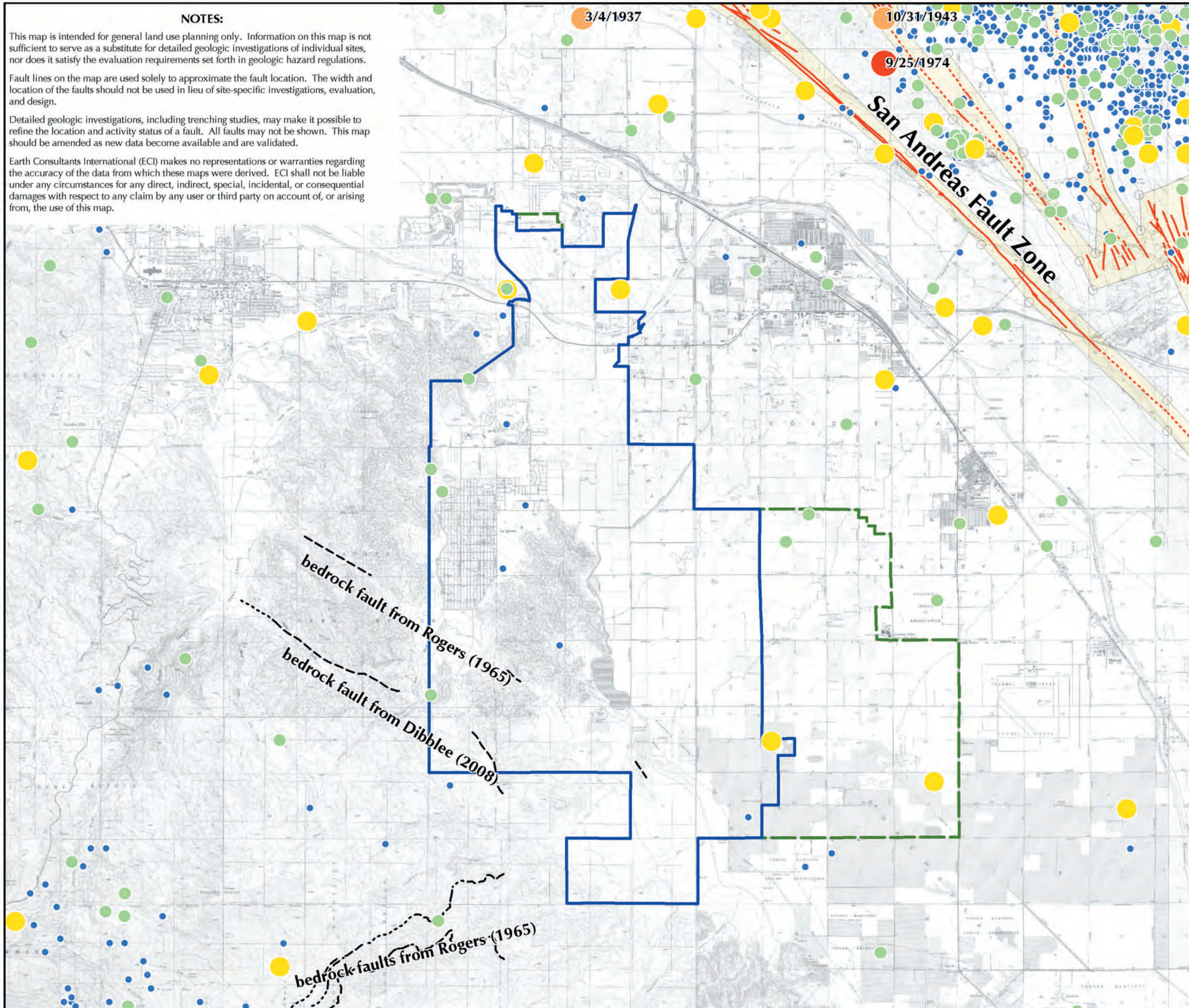

Faults and Historical (1800-2010) Seismicity Map

La Quinta, California

Explanation

Earthquake Magnitude

- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- <2

Active Fault; solid where well located, dashed where approximately located, dotted where concealed or inferred.

Bedrock (not active) Fault; dashed where approximately located, dotted where concealed or inferred.

Alquist-Priolo Earthquake Fault Zone; boundaries delineated as straight-line segments that connect encircled turning points. From CGS, 2002.

La Quinta City Boundary

La Quinta Sphere of Influence

N
W E
S

8000 0 8000 Feet

2000 0 2000 Meters

Scale: 1:96,000

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997.
Sources: Southern California Earthquake Center (January 1932 to April 2010); National Earthquake Information Center (1800 to 1931); Alquist-Priolo Earthquake Fault Zones [Reproduced with permission CGS CD-ROM 2001-05 (2002)]; Rogers, 1965; Matti and others, 1983; and Dibblee, 2008.

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La Quinta 2035 GENERAL PLAN UPDATE

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Date: 2010

Plate 1-1

revised, alluvium), and Boore et al. (1997; with NEHRP soil type D). The ground motions presented here are the average of the acceleration values calculated using these two attenuation equations. Based on the ground shaking analyses described above, those faults that can cause peak horizontal ground accelerations of about 0.1g or greater (Modified Mercalli Intensities greater than VII) in the La Quinta area are listed in Table 1-2. For maps showing most of these faults, refer to Figures 1-1 and 1-2. Those faults included in Table 1-2 that could have the greatest impact on the La Quinta area, or that are thought to have a higher probability of causing an earthquake, are described in more detail in the following pages. The deterministic analyses indicate that the San Andreas fault, and to a lesser degree the San Jacinto fault, have the potential to generate strong to moderate ground shaking in La Quinta, with PGHA (median) of between 0.21g and 0.66g (between 0.32g and 1.06g at the median plus 1 sigma standard deviation level). Shaking at these levels can cause significant damage to older structures, and moderate damage to newer buildings constructed in accordance with the latest building code provisions.

Table 1-2 shows:

- The approximate distance, in miles and kilometers, between the fault and various points in the La Quinta area, given as a range. Since these measurements are based on specific, but randomly selected points in the study area; other points in the city could be closer or farther away from the faults than the distances provided herein;
- The maximum magnitude earthquake (M_{max}) each fault is estimated capable of generating;
- The range in peak ground horizontal accelerations (PGHA), provided both for the median (50th percentile) and median plus 1 sigma standard deviation (84th percentile), or intensity of ground motion, expressed as a fraction of the acceleration of gravity (g), that could be experienced in different areas of La Quinta if the M_{max} occurs on the faults listed; and
- The range in Modified Mercalli seismic Intensity (MMI) values estimated for the La Quinta area.

The peak ground horizontal accelerations and intensities summarized in Table 1-2 are shown from largest to lowest for each fault; these should be considered as average values, since different areas of La Quinta are expected to feel and respond to each earthquake differently in response to site-specific conditions. As mentioned before, peak ground accelerations and seismic intensity values decrease with increasing distance away from the causative fault. However, local site conditions, such as reflection off of the hard rock forming the mountains in the region, can amplify the seismic waves generated by an earthquake, resulting in localized higher accelerations than those listed here. Please note that the PHGA analyses conducted for this study provide a general indication of relative earthquake risk throughout the La Quinta General Plan area. For individual projects however, site-specific analyses that consider the precise distance from a given site to the various faults in the region, as well as the local near-surface soil types, should be conducted.

Table 1-2: Estimated Horizontal Peak Ground Accelerations and Seismic Intensities in the La Quinta Area

Fault or Fault Segment	Distance to La Quinta (mi)	Distance to La Quinta (km)	Magnitude of M_{max}	PGHA (g) from M_{max} (median, median + 1 sigma)	MMI from M_{max}
San Andreas fault (entire Southern)	3.4 – 8.8	5.4 – 14.2	8.0	0.50 – 0.34, 1.06 – 0.73	XII - X
San Andreas (Coachella segment)	3.4 – 8.8	5.4 – 14.2	7.2	0.50 – 0.36 0.79 – 0.52	XI - IX
San Andreas (Coachella + San Bernardino)	3.4 – 8.8	5.4 – 14.2	7.7	0.6 – 0.41, 0.95 – 0.65	XII - X
San Andreas (San Bernardino)	17.6 – 28.2	28.4 – 45.4	7.5	0.23 –0.15, 0.36 –0.25	IX - VIII
San Jacinto (Anza)	16.3 – 23.4	26.3 – 37.7	7.2	0.21 – 0.15, 0.32 – 0.24	IX – VIII
Burnt Mountain	15.4 – 26.2	24.8 – 42.2	6.5	0.14 – 0.08, 0.23 – 0.14	IX - VI
Eureka Peak	16 – 26.7	25.8 - 43	6.4	0.14 – 0.08, 0.21 – 0.14	IX - VI
San Jacinto (Coyote Creek)	18 –23.8	29 – 38.3	6.6	0.13 – 0.10, 0.21 – 0.17	IX – VII
Pinto Mountain	28 – 37.8	45.1 – 60.9	7.2	0.13 – 0.09, 0.21 – 0.16	IX – VII
Pisgah – Bullion	31.5 – 39.5	50.7 – 63.6	7.3	0.12 – 0.09, 0.2 – 0.16	VIII - VI

Abbreviations used in Table 1-2:
mi – miles; **km** – kilometer; **M_{max}** – maximum magnitude earthquake; **PGHA** – peak ground horizontal acceleration as a percentage of **g**, the acceleration of gravity; **MMI** – Modified Mercalli Intensity.

Several other faults have the potential to generate seismic shaking similar to that experienced in La Quinta during the 1992 Landers earthquake. Faults that would generate a similar level of shaking include: North Frontal (both East and West segments, individually), Calico-Hidalgo, Elsinore (Julian segment), Lenwood-Lockhart-Old Woman Springs, Helendale-South Lockhardt, San Jacinto (San Jacinto Valley segment), San Jacinto (Borrego segment), Brawley Seismic Zone, Earthquake Valley, and Elmore Ranch. All of these faults would generate peak ground accelerations in the 0.05 to 0.09 range (median) and 0.08 to 0.16 range (median plus 1 sigma), with Modified Mercalli intensities in the V to VIII range.

The ground motions presented in Table 1-2 are based on the largest earthquake that each fault, or fault segment, is believed capable of generating, referred to as the ***maximum magnitude earthquake*** (M_{max} – as assigned by the California Geological Survey, although some researchers believe some of these faults can generate even larger events). This deterministic approach is useful to study the effects of a particular earthquake on a building or community. However, since many potential earthquake sources can shake the region, it is also important to consider the overall likelihood of damage from a plausible suite of earthquakes. This approach is called probabilistic seismic hazard analysis (PSHA), and typically considers the likelihood of exceeding a certain level of damaging ground motion that could be produced by any or all faults within a given radius of the project site, or in this case, the city. Most seismic hazard analyses consider a distance of 100 km (62 miles), but this is arbitrary. PSHA has been utilized by the U.S. Geological Survey to produce national seismic hazard maps such as those used by the Uniform Building Code (ICBO, 1997), the International Building Code (ICC, 2006) and the California Building Code (CBSC, 2007).

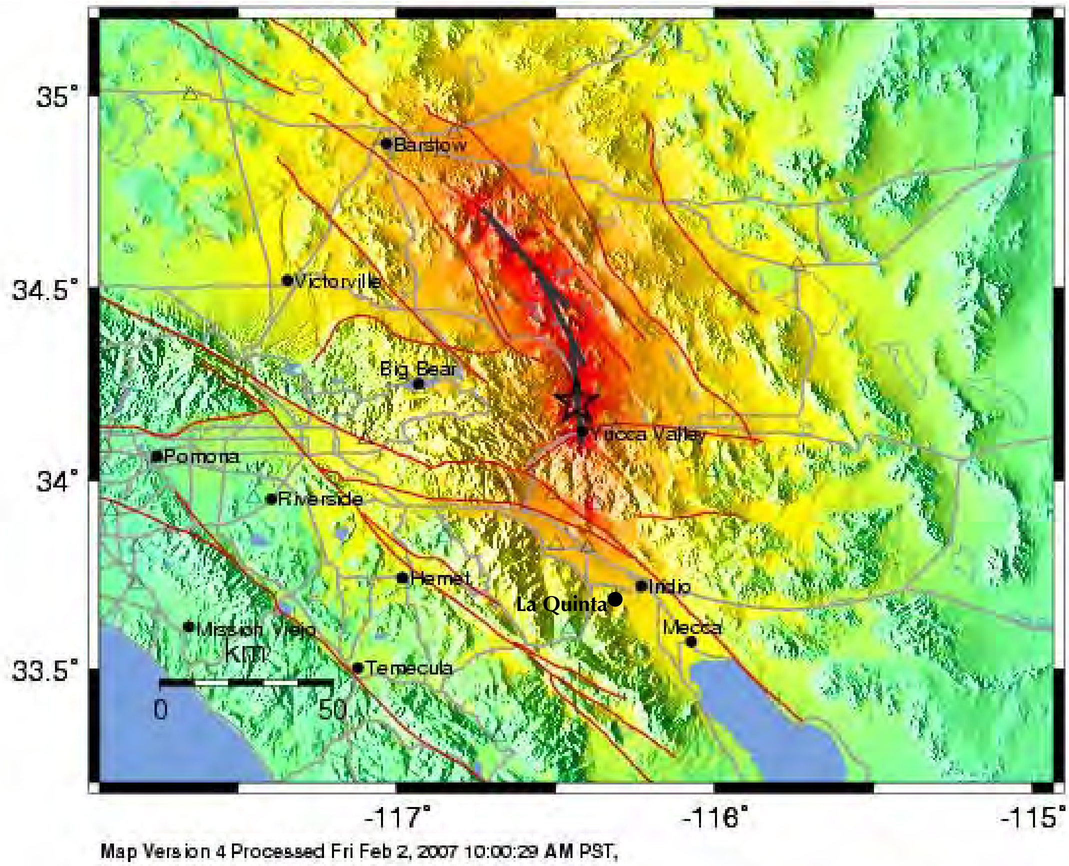
We ran the interactive ground motion module from the California Geological Survey (http://www.consrv.ca.gov/CGS/rghm/pshamap/pshamap.asp) and that by the U.S. Geological Survey (http://earthquake.usgs.gov/research/hazmaps/design/) to estimate the ground motions that have a 10% and 2% probability, respectively, of being exceeded in 50 years in the vicinity of City Hall. [Seismic design parameters in the 2007 California Building Code are based on the maximum considered earthquake, with a ground motion that has a 2% probability of being exceeded in 50 years and a recurrence interval of about 2,500 years.] For La Quinta, the estimated level of ground motion that has a 10% probability of being exceeded in 50 years near City Hall is about 0.5g. The level of ground motion with a 2% probability of being exceeded in 50 years is about 0.8g. The ground motions at a site near the northeast corner of the city with a 10% and 2% probability of being exceeded in 50 years are 0.64g and 1.09g, respectively. This is the area of the city closest to the San Andreas fault, the principal source responsible for these levels of shaking, and a fault that has a relatively high probability of rupturing in the next 30 years. These levels of shaking are in the moderate to very high range for southern California, and can be expected to cause moderate to heavy damage, particularly to older and poorly constructed buildings.

Regardless of which fault causes a damaging earthquake, there will always be ***aftershocks***. By definition, these are smaller earthquakes that happen close to the ***mainshock*** (the biggest earthquake of the sequence) in time and space. These smaller earthquakes occur as the Earth adjusts to the regional stress changes created by the mainshock. As the size of the mainshock increases, there typically is a corresponding increase in the number of aftershocks, the size of the aftershocks, and the size of the area in which they might occur.

On average, the largest aftershock will be 1.2 magnitude units less than the mainshock. Thus, a M_W 6.9 earthquake will tend to produce aftershocks up to M_W 5.7 in size. This is an average, and there are many cases where the biggest aftershock is larger than the average predicts. The key point is this: any major earthquake will produce aftershocks large enough to cause additional damage, especially to already-weakened structures. Consequently, post-disaster response planning must take damaging aftershocks into account.

Another way to communicate the seismic shaking hazard is with the use of ShakeMaps. A ShakeMap is a representation of the various levels of ground shaking throughout the region where an earthquake occurs. ShakeMaps are compiled from the California Integrated Seismic Network (CISN) – a network of seismic recording instruments placed throughout the state – and are automatically generated following moderate to large earthquakes. Preliminary real-time maps are posted within minutes on the Internet (http://earthquake.usgs.gov/eqcenter/shakemap/) giving disaster response personnel an immediate picture of where the most damage likely occurred. Although several shaking parameters can be illustrated on ShakeMaps, such as peak acceleration and peak velocity, most people can relate more easily to maps illustrating the *intensity* of ground shaking. Using actual instrumental ground motion recordings and comparing them to observed Modified Mercalli Intensities from recent California earthquakes, scientists can now estimate shaking intensities within a few minutes after an earthquake. Figure 1-4 shows the ShakeMap generated by the U.S. Geological Survey for the 1992 Landers earthquake. Notice the strong level of shaking reported for the Coachella Valley area, including La Quinta.

Figure 1-4: Modified Mercalli Intensity ShakeMap for the June 28, 1992 Landers Earthquake



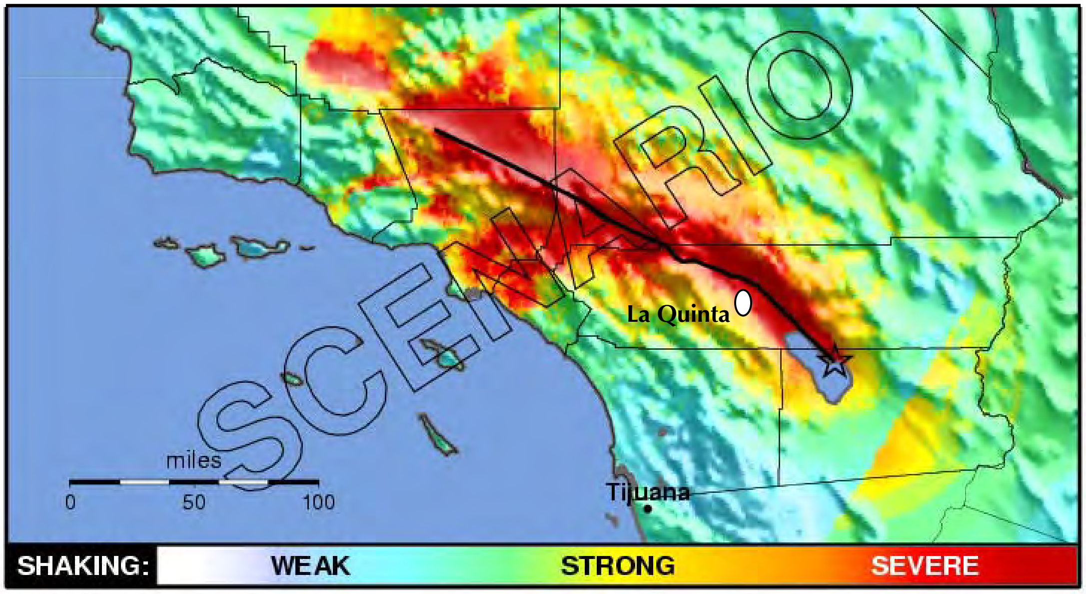
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: http://earthquake.usgs.gov/earthquakes/shakemap/sc/shake/Landers/

ShakeMaps can also be used for planning and emergency preparedness by creating hypothetical earthquake scenarios. These scenarios are not predictions – knowing when or how large an earthquake will be in advance is still not possible. However, using realistic assumptions about the size and location of a future earthquake, we can make predictions of its effects, and use this information for loss estimations and emergency response planning. Figure 1-5 is an Intensity ShakeMap for the hypothetical magnitude 7.8 "Shakeout" earthquake scenario that involves rupture of the entire southern San Andreas fault, from the Salton Sea northward to Lake Hughes, in northern Los Angeles County. At its closest, the San Andreas fault would rupture approximately

3.4 miles east-northeast of La Quinta. The ShakeMap shows that the area in and around La Quinta would experience severe shaking.

Figure 1-5: ShakeMap for a Magnitude 7.8 Earthquake Scenario on the Southern San Andreas Fault



Source: http://earthquake.usgs.gov/eqcenter/shakemap/sc/shake/ShakeOut2_full_se/#Decorated

The most significant faults in Table 1-2 are discussed in greater detail in the pages below.

1.4.1 San Andreas Fault Zone

The San Andreas fault is the principal boundary between the Pacific and North American plates. The fault extends over 1,100 km (690 miles), from near Cape Mendocino in northern California to the Salton Sea region in southern California. This fault is considered the "Master Fault" in southern California because it has frequent, large earthquakes and controls the seismic hazards of the area. Many refer to an earthquake on the San Andreas fault as "The Big One," and for many parts of southern California, including La Quinta, this designation is indeed true. Other areas closer to the coastline are actually at greater risk from other faults. Nevertheless, the San Andreas fault should be considered in all seismic hazard assessment studies in southern California given its high probability of causing an earthquake in the near future. A group of scientists referred to as the 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008) has calculated that the southern San Andreas fault has a 59% probability of causing an earthquake of at least magnitude 6.7 in the next 30 years.

Large faults, such as the San Andreas fault, are often divided into segments in order to evaluate their future earthquake potential. The segmentation is based on physical characteristics along the fault, particularly discontinuities that may affect the rupture length. The southern and central San Andreas fault is now divided into ten segments named, from north to south, Parkfield, Cholame, Carrizo, Big Bend, Mojave North, Mojave

South, San Bernardino North, San Bernardino South, San Gorgonio-Garnet Hill, and Coachella (WGCEP, 2008). The southernmost segments are discussed further below.

Each segment is assumed to have a characteristic slip rate (rate of movement averaged over time), recurrence interval (time between moderate to large earthquakes), and displacement (amount of offset during an earthquake). While this methodology has some value in predicting earthquakes, historical records and studies of prehistoric earthquakes show it is possible for more than one segment to rupture during a large quake or for ruptures to overlap into adjacent segments. For example, the last major earthquake on the southern portion of the San Andreas fault (and the largest earthquake reported in California) was the 1857 Fort Tejon (M 8) event. The 1857 earthquake ruptured the Cholame, Carrizo, and Mojave segments of the fault, resulting in displacements of as much as 27 feet (9 meters) along the rupture zone. These fault segments are thought to have a recurrence interval of between 104 and 296 years. Peak ground accelerations in La Quinta as a result of the 1857 earthquake are estimated at about 0.07g, a fairly low level of shaking. However, if the entire southern San Andreas fault, including, from south to north, the Coachella, San Gorgonio-Garnet Hill, San Bernardino and Mojave segments, ruptured in an earthquake with its epicenter along that section of the San Andreas fault closest to La Quinta, the resulting shaking in the city would be severe to violent, with peak ground accelerations estimated at between about 0.5g and 1.1g (see Table 1-2 and Figure 1-5). This is the worst-case earthquake scenario for the city of La Quinta.

The **Coachella** and **San Gorgonio-Garnet Hill** sections combined extend about 124 km, from Bombay Beach in the Salton Sea to San Gorgonio Pass. The straight Coachella segment is predominantly strike-slip in character, whereas the San Gorgonio-Garnet Hill section is very complex, and appears to be oblique strike-slip, with a major thrust component of movement (Yule and Sieh, 2003). The Coachella segment has not produced any large surface-rupturing earthquakes in historic times (Sieh and Williams, 1990); paleoseismic studies suggest that the last surface-rupturing earthquake on this segment occurred around A.D 1680. The San Gorgonio-Garnet Hill section is thought to have last ruptured in 1812, although additional studies need to be conducted to confirm this (Yule et al., 2006; Dawson et al., 2008). Paleoseismic data also suggest that the Coachella, San Gorgonio Pass and San Bernardino segments ruptured simultaneously in earthquakes that occurred around A.D. 1500, and possibly A.D. 1680 (Dawson et al., 2008, summarizing data by Fumal et al., 2002, Yule et al., 2006, and McGill et al., 2002). Using a slip rate of 25 ± 5 mm/yr and a characteristic displacement of 4.0 +4,-2 meters, the 1995 WGCEP derived a recurrence interval of 220 ±13 years for the Coachella segment. More recently, the 2007 WGCEP assigned a slip rate of 20±6 mm/yr to the Coachella segment, and a slip rate of 10±6 mm/yr to the San Gorgonio-Garnet Hill section. Rupture of the Coachella and San Gorgonio Pass-Garnet Hill fault segments in a magnitude 7.2 earthquake is estimated capable of generating peak ground accelerations in La Quinta of about 0.4g to 0.8g. If the Coachella, San Gorgonio Pass-Garnet Hill and San Bernardino sections rupture together in a magnitude 7.7 earthquake, La Quinta would experience peak ground accelerations of between 0.4g and 1.0 g. These are strong to very strong ground motions.

The **San Bernardino segments** combined are about 43 miles (70 km) long and extend from the San Gorgonio Pass northward to approximately Cajon Pass. Slip rate on the San Andreas fault in this area decreases southward. At the north end of the San Bernardino

North segment, in the area of Cajon Pass and Pittman Canyon, the fault has a slip rate of 22±6 mm/yr. To the south, some of the slip is being transferred to the San Jacinto fault through the Crafton Hills fault and related structures, so that slip on the San Bernardino South segment is estimated at 16±6 mm/yr (WGCEP, 2008). Both segments appear to have last ruptured in 1812. If both sections rupture together in the future, the resultant magnitude 7.5 earthquake could cause peak ground accelerations in La Quinta of between 0.15g and 0.36g. If, as discussed above, the San Bernardino segments rupture in conjunction with the Mojave and/or Coachella segments, higher ground motions would be expected in the region.

1.4.2 San Jacinto Fault Zone

The San Jacinto fault zone consists of a series of closely spaced faults that form the western margin of the San Jacinto Mountains. The zone is about 280 km (175 miles) in length and extends from its junction with the San Andreas fault in San Bernardino, southeasterly toward the Brawley area, where it continues south of the international border as the Imperial fault. The San Jacinto fault has historically produced more large earthquakes than any other fault in southern California, although none of these earthquakes has been as large as the 1857 and 1906 earthquakes on the San Andreas fault. The two most-recent surface-rupturing earthquakes on the San Jacinto fault were the April 9, 1968, M_w 6.5 on the Coyote Creek segment (Jennings, 1994), and the 1987 event on the Superstition Hills segment. Offset across the fault traces is predominantly right-lateral strike-slip, similar to the San Andreas fault, although Brown (1990) has suggested that vertical motion contributes up to 10% of the net slip.

The San Jacinto fault zone has been divided into seven segments. From north to south these include the San Bernardino Valley, San Jacinto Valley, Anza, Coyote Creek, Borrego Mountain, Superstition Hills and Superstition Mountain segments. Each segment, in turn, consists of a series of subparallel faults. Fault slip rates on the various segments of the San Jacinto fault are less well constrained than for the San Andreas fault, but the data available suggest right-lateral slip rates of 12±6 mm/yr for the northern segments of the fault and slip rates of 4±2 mm/yr for the southern segments (WGCEP, 1995). This amounts to between about 12% and 30% of the total slip on the San Andreas fault system. The Working Group on California Earthquake Probabilities (1995) gave the San Bernardino and San Jacinto Valley segments a 37% and 43% probability, respectively, of rupturing sometime between 1994 and 2024. These probabilities were reduced somewhat by the WGCEP (2008), to an average of 31% for all segments of the San Jacinto fault. The segments of the San Jacinto fault closest to La Quinta include the Anza and Coyote Creek. These segments are discussed further below.

The segment of the San Jacinto fault closest to La Quinta is the **Anza segment**. This section of the fault has been studied extensively at Hog Lake, where at least 16 past earthquakes have been resolved from the faulted stratigraphy (WGCEP, 2008 based on data provided by T. Rockwell). The data indicate an average recurrence interval of 238 years for this segment, with the most recent earthquake having occurred between about A.D. 1775 and A.D. 1805. A M_w 7.2 earthquake on this segment would generate peak ground accelerations in the La Quinta area of between about 0.15g and 0.32g.

The next section to the south, the **Coyote Creek segment**, is about 22 miles (40 km) long. There are no paleoseismic data for this segment, so independent fault parameters, such as slip rate and recurrence interval, are not available. Assuming that this segment is similar to the sections to the south, including the Borrego Mountain and Superstition Hills segments, the Coyote Creek segment is thought to have a slip of 4±2 mm/yr and a recurrence interval of about 175 years (WGCEP, 1995). A M_w 6.6 earthquake on this segment of the San Jacinto fault would generate peak ground accelerations in La Quinta of between about 0.10g and 0.21g.

1.4.3 Burnt Mountain Fault

Like several of the other Eastern Mojave Shear Zone faults, the Burnt Mountain fault was unknown prior to late June 1992, when a 3.1-mile- (5 km) length of this fault ruptured at the ground surface, probably during a large aftershock of the Landers earthquake, experiencing about 2.4 inches (6 cm) of right-lateral offset. Geologists later mapped this area and determined that the Burnt Mountain fault has a total length of about 13 miles (21 km). Given its overall length, this fault is thought capable of producing a magnitude 6.0 to 6.5 earthquake (Wesnousky, 1986). The Burnt Mountain fault is at its closest approach about 15 miles to the north of La Quinta. An estimated M_w 6.5 earthquake on this fault could generate horizontal ground accelerations in the La Quinta area of between about 0.08g and 0.21g, with the higher accelerations occurring in the northern portions of the city closest to the fault. The level of damage anticipated would be consistent with Modified Mercalli intensities of between VI and IX.

1.4.4 Eureka Peak Fault

The Eureka Peak fault is a right-lateral strike-slip fault about 12.5 to 15 miles (20 to 25 km) in length that last ruptured, together with other faults, during the 1992 Landers earthquake. Only about 6 miles (10 km) of the fault ruptured at that time, but this allowed geologists to discover the fault and map its full length. Maximum offset on this fault in 1992 was 21 cm; geologists think that this slip occurred in two separate but closely spaced events, plus some afterslip. The first rupture is thought to have occurred about 30 seconds after the Landers mainshock, whereas the second rupture episode was probably as a result of a magnitude 5.6 aftershock that occurred less than three minutes after the mainshock. Researchers have also suggested that the Joshua Tree earthquake of April 22, 1992 was caused by this fault (Jones et al., 1995). The Southern California Earthquake Center estimates that the Eureka Peak fault is capable of generating earthquakes of moment magnitude between 5.5 and 6.8. A M_w 6.4 earthquake on this fault is estimated capable of generating horizontal peak ground accelerations in La Quinta of between 0.08g and 0.21g.

1.4.5 Pinto Mountain Fault

The Pinto Mountain fault is a prominent left-lateral strike-slip fault that bounds the north side of the Little San Bernardino Mountains, about 28 miles north-northwest of the city of La Quinta at its closest approach. The fault is at least 45 miles (73 km) long, and possibly as much as 56 miles (90 km). Recent studies show that this fault has ruptured repeatedly in the last 14,000 years, with at least four events within the last about 9,400 years (Cadena et al., 2004). The fault is therefore active under the provisions of the Alquist-Priolo Act. Current estimates on its rate of slip suggest a rate of between 1.1 and 2.3 mm/yr. Additional studies should refine those estimates further. A magnitude 7.2 earthquake on this fault could generate peak horizontal ground acceleration in La Quinta of about 0.09g to 0.21g. Such an earthquake would cause damage typical of Modified Mercalli intensities between VII and IX in the city. An even larger, magnitude 7.5, earthquake on the Pinto Mountain fault would generate stronger ground shaking in the La Quinta area.

1.4.6 Pisgah – Bullion Mountain – Mesquite Lake Fault Zone

The Pisgah fault is a 34-km- (21 miles) long, right-lateral strike-slip fault that experienced triggered slip in 1992 as a result of shaking from the Landers earthquake. The fault is thought to have last moved in the Holocene, but the interval between surface-rupturing earthquakes is unknown. The fault is thought to have a slip of about 0.8 mm/yr, but geologic studies need to be conducted to confirm these estimates. If only the Pisgah fault ruptured in an earthquake, the resulting event would have a magnitude M_w between 6.0 and 7.0. However, the Pisgah fault may also rupture together with the 55-km- (34 miles) long Bullion fault to the south, and the 40-km- (22 miles) long Mesquite Lake fault farther south. The Bullion fault last ruptured on October 16, 1999 during the M_w 7.1 Hector Mine earthquake. Prior to that, both the Bullion and Mesquite Lake faults appear to have ruptured during a large earthquake in the mid to late Holocene (Madden and others, 2006).

Recent studies of the Mesquite Lake fault have shown that this fault has had three large surface-rupturing earthquakes in the past about 10,200 years, each creating an apparent vertical offset of between 1.0 and 1.2 meters, suggesting similar-sized earthquakes. The trenching data indicates this fault has a horizontal slip rate of between 0.7 and 0.9 mm/yr, consistent with the slip rates estimated for several other faults in the Eastern California Shear Zone. The paleoseismic data also seem to suggest that earthquakes on this fault occur in clusters, separated by seismically quiet periods that last several thousands of years, and that seismic activity in the shear zone flip flops between the eastern and western faults in the region (Madden and others, 2006).

A magnitude 7.3 earthquake is estimated if all three fault segments – the Pisgah, Bullion Mountain and Mesquite Lake – ruptured together. An earthquake of that size on these faults would generate peak horizontal ground accelerations in the La Quinta area of about 0.09g to 0.2g, with Modified Mercalli intensities of VI to VIII.

1.4.7 Elsinore Fault Zone

The Elsinore fault is a major right-lateral strike-slip fault that extends from northern Baja California to the Los Angeles Basin, a distance of approximately 306 km (190 miles) (Treiman, 1998). As part of the San Andreas fault system in southern California, the Elsinore fault accommodates about 10% of the motion between the Pacific and North American plates (WGCEP, 1995), with a slip of about 5 mm/yr (Bergmann et al., 1993; Millman and Rockwell, 1986; Vaughan and Rockwell, 1986). The 2007 Working Group on California Earthquake Probabilities (WGCEP, 2008) assigned the Elsinore fault an 11% probability of rupturing in a M>6.7 earthquake in the next 30 years.

The fault is divided, from south to north into the Laguna Salada, Coyote Mountain, Julian, Temecula, Glen Ivy, Chino, and Whittier segments (Treiman, 1998). The section closest to La Quinta is the **Julian segment**, which at its closest approach is about 39 miles to the west. The 35-miles (65 km) long Julian segment is the longest section of the Elsinore fault zone. Its north end is defined by a restraining bend, whereas at its south end, it steps across a 4- to 5-km wide area to the Coyote Mountain section. The most recent surface-rupturing earthquake on this section appears to have occurred about 1,500 years ago, and the penultimate event about 3,000 years ago. There are too few earthquakes resolved on this segment to calculate a recurrence interval. If the Julian segment of the Elsinore fault ruptured in a M 7.1 earthquake, peak ground motions of about 0.08g are anticipated in the La Quinta area.

1.5 Surface Fault Rupture

1.5.1 Definitions

Primary fault rupture refers to fissuring and displacement of the ground surface along a fault that breaks in an earthquake. Primary fault rupture is rarely confined to a simple line along the fault trace. As the rupture reaches the ground surface, it commonly spreads out into complex fault patterns of secondary faulting and ground deformation. In the 1992 Landers earthquake, the zone of deformation around the main trace was locally hundreds of feet wide (Lazarte and others, 1994). Surface displacement and distortion associated with secondary faulting and deformation can be relatively minor or can be large enough to cause significant damage to structures.

Primary ground rupture due to fault movement typically results in a relatively small percentage of the total damage in an earthquake, yet being too close to a rupturing fault can result in extensive damage. It is difficult and generally costly to safely reduce the effects of this hazard through building and foundation design. Therefore, the preferred, and traditional mitigation measure for this hazard is to avoid active faults by setting structures back from the fault zone. In California, application of this measure is subject to requirements of the Alquist-Priolo Earthquake Fault Zoning Act and guidelines prepared by the California Geological Survey – previously known as the California Division of Mines and Geology (CGS Note 42 by Hart and Bryant, 2007). The final approval of a fault setback lies with the local reviewing agency.

Secondary fault rupture refers to ground surface displacements along faults other than the main traces of active regional faults. Secondary ground deformation includes fracturing, shattering, warping, tilting, uplift and/or subsidence. Unlike the regional faults, most subsidiary faults are not deeply rooted in the Earth's crust and are not capable of producing damaging earthquakes on their own. Movement along these faults generally occurs in response to movement on a nearby regional fault. Yet, the zone of secondary faulting can be quite large, even in a moderate-sized earthquake. For instance, in the 1971 San Fernando quake, movement along subsidiary faults occurred as much as 2 km from the main trace (Ziony and Yerkes, 1985). Triggered slip as a result of a regionally large earthquake can also occur in faults many kilometers away from the causative fault. For example, as a result of the 1992 Landers earthquake, triggered surface slips were documented in the Coachella Valley area (Rymer, 2000). Similarly, following the 1999 Hector Mine earthquake, triggered surface slips were recorded in the Salton Trough (Rymer et al., 2002; Meltzner et al., 2006). More recently, as a result of the April 4, 2010 Sierra El Mayor earthquake in Baja California, triggered slip was reported on the San Andreas, Superstition Hills, Imperial and Brawley fault zones.

Faults have formed over millions of years, usually in response to regional stresses. Shifts in these stress regimes do occur over millennia. As a result, some faults change in character. For example, a thrust fault in a compressional environment may become a strike-slip fault in a transpressive (oblique compressional) environment. Other faults may be abandoned altogether, and previously not active faults may be reactivated. Consequently, the State of

California, under the guidelines of the Alquist-Priolo Earthquake Fault Zoning Act of 1972 (Hart and Bryant, 1999, 2007), classifies faults according to the following criteria:

- ***Active***: faults showing proven displacement of the ground surface within about the past about 11,000 years (within the Holocene Epoch), that are thought capable of producing earthquakes;

- ***Potentially Active***: faults showing evidence of movement within the past 1.6 million years, but that have not been shown conclusively whether or not they have moved in the past 11,000 years; and

- ***Not active***: faults that have conclusively NOT moved in the past 11,000 years.

The Alquist-Priolo classification is used primarily for residential subdivisions. Different definitions of activity are used by other agencies or organizations depending on the type of facility being planned or developed. For example, longer periods of inactivity are generally required for dams or nuclear power plants. Faults that have ruptured historically form an important subset of active faults. In California, that generally means faults that have ruptured since 1769, when the Spanish first arrived and settled in the area. However, since many parts of the State were not settled until well into the middle of the 1800s, some historical earthquakes most likely went un-noticed and therefore unreported.

The underlying assumption in this classification system is that if a fault has not ruptured in the past about 11,000 years, it is not likely to be the source of a damaging earthquake in the future. In reality, however, most potentially active faults have been insufficiently studied to determine their hazard level. For example, some of the faults that ruptured in the 1992 Landers and 1999 Hector Mine earthquakes were previously thought to be not active, as they appeared to have not moved in at least 11,000 years. Also, although simple in theory, the evidence necessary to determine whether a fault has or has not moved during the past 11,000 years can be difficult to obtain.

In most cases, it is impractical to reduce the damage potential of surface fault rupture by engineering design, and most regulatory agencies, following the position of the California Geological Survey, currently do not allow engineering design for habitable structures (although this is being reconsidered for “minor” faults at this time). Therefore, the most often-used mitigation measure is to simply avoid placing structures on or near active fault traces. The Alquist-Priolo Earthquake Fault Zones Act requires that geologic investigations, which generally include fault trenching or some other method of subsurface analysis, be performed if conventional structures designed for human occupancy are proposed within a fault zone. These studies must evaluate whether or not an active segment of the fault extends across the area of proposed development following the guidelines for evaluating the hazard of fault rupture presented in Note 49, a publication by the CGS that is available on the world wide web at http://www.consrv.ca.gov/CGS/rghm/ap/index.htm.

Based on the results of these geologic studies, appropriate structural setbacks are recommended to prevent the siting of the proposed structures directly on top or within a certain distance from the fault. A common misperception regarding setbacks is that they are always 50 feet from the active fault trace. In actuality, as part of a geologic investigation, the project geologist is required to characterize the ground deformation associated with an active fault. Based on these studies, specific setbacks are recommended. If a fault trace is narrow, with little or no associated ground deformation, a setback distance less than 50 feet could be recommended. Conversely, if the fault zone is wide, with multiple splays, or is poorly defined, a setback distance greater than 50 feet may be warranted.

1.5.2 Faults in the La Quinta Area

There is one main fault zoned by the State of California under the criteria of the Alquist-Priolo Act near but outside the La Quinta General Plan area: the San Andreas fault zone, which is located to the north and northeast of the city (see Plate 1-1).

Although a few bedrock faults have been mapped beneath and within the city of La Quinta (Rogers, 1965; Jennings, 1994; Dibble, 2008; see Plate 1-1), these faults do not impact the Quaternary deposits, and are therefore not considered active or potentially active. Thus, no active faults have been zoned under the guidelines of the Alquist-Priolo Act in the La Quinta General Plan area proper.

1.6 Ground Failure due to Earthquake Shaking

Various types of ground failure that are the result of earthquake shaking can cause substantial damage to the built environment. The most destructive of these failures include liquefaction and slope failure, but other tectonically induced forms of ground failure are also possible. These are described further below.

1.6.1 Liquefaction

Liquefaction is a geologic process that causes various types of ground failure. It typically occurs within the upper 50 feet of the surface, in saturated, loose, fine- to medium-grained sandy to silty soils in the presence of ground accelerations over 0.2g (Borchardt and Kennedy, 1979; Tinsley and Fumal, 1985). Earthquake shaking suddenly increases pressure in the water that fills the pores between soil grains, causing the soil to have a total or substantial loss of shear strength, and behave like a liquid or semi-viscous substance. This process can be observed at the beach by standing on the wet sand near the surf zone. Standing still, the sand will support our weight. However, if we tap the sand with our feet, water comes to the surface, the sand liquefies, and our feet sink.

Liquefaction can cause structural distress or failure due to ground settlement, a loss of bearing capacity in the foundation soils, and the buoyant rise of buried structures. That is, when soils liquefy, the structures built on them can sink, tilt, and suffer significant structural damage. In addition to loss of bearing strength, liquefaction-related effects include ground oscillations, lateral spreading and flow failures or slumping. The excess water pressure is relieved by the ejection of material upward through fissures and cracks; water or water-soil slurries may bubble onto the ground surface, resulting in features called "sand boils," "sand blows," "sand volcanoes," or "mud spouts." Seepage of water through cracks may also be observed.

The types of ground failure typically associated with liquefaction are explained below.

Lateral Spreading – Lateral displacement of surficial blocks of soil as the result of liquefaction in a subsurface layer is called lateral spreading. Even a very thin liquefied layer can act as a hazardous slip plane if it is continuous over a large enough area. Once liquefaction transforms the subsurface layer into a fluid-like mass, gravity plus inertial forces caused by the earthquake may move the mass down-slope towards a cut slope or free face (such as a river channel or a canal). Lateral spreading most commonly occurs on gentle slopes that range between 0.3 degrees and 3 degrees, and can displace the ground surface by several feet to tens of feet. Such movement damages pipelines, utilities, bridges, roads, and other structures. During the 1906 San Francisco earthquake, lateral spreads with displacements of only a few feet damaged every major pipeline in the area. Thus, liquefaction compromised San Francisco's ability to fight the fires that caused about 85% of the damage (Tinsley and others, 1985). Lateral spreading was also reported in and around the Port of Los Angeles during both the 1933 and 1994 earthquakes (Barrows, 1974; Stewart and others, 1994; Greenwood, 1998).

Flow Failure – The most catastrophic mode of ground failure caused by liquefaction is flow failure. Flow failure usually occurs on slopes greater than 3 degrees. Flows are principally liquefied soil or blocks of intact material riding on a liquefied subsurface. Displacements are often in the tens of meters, but under favorable circumstances, soils can be displaced for tens of miles, at velocities of tens of miles per hour. For example, the extensive damage to Seward and Valdez, Alaska, during the 1964 Great Alaskan earthquake was caused by submarine flow failures (Tinsley and others, 1985).

Ground Oscillation – When liquefaction occurs at depth but the slope is too gentle to permit lateral displacement, the soil blocks that are not liquefied may separate from one another and oscillate on the liquefied zone. The resulting ground oscillation may be accompanied by the opening and closing of fissures (cracks) and sand boils, potentially damaging structures and underground utilities (Tinsley and others, 1985).

Loss of Bearing Strength – When a soil liquefies, loss of bearing strength may occur beneath a structure, possibly causing the building to settle and tip. If the structure is buoyant, it may float upward. During the 1964 Niigata, Japan earthquake, buried septic tanks rose as much as 3 feet, and structures in the Kwangishicho apartment complex tilted as much as 60 degrees (Tinsley and others, 1985).

Ground Lurching – Soft, saturated soils have been observed to move in a wave-like manner in response to intense seismic ground shaking, forming ridges or cracks on the ground surface. At present, the potential for ground lurching to occur at a given site can be predicted only generally. Areas underlain by thick accumulation of colluvium and alluvium appear to be the most susceptible to ground lurching. Under strong ground motion conditions, lurching can be expected in loose, cohesionless soils, or in clay-rich soils with high moisture content. In some cases, the deformation remains after the shaking stops (Barrows and others, 1994).

As indicated above, there are three general conditions that need to be met for liquefaction to occur. The first of these –ground shaking of relatively long duration – can be expected to occur in the La Quinta area as a result of an earthquake on the San Andreas, San Jacinto, Burnt Mountain, and some of the other active faults in the region. The second condition – geologically young, loose, unconsolidated sediments – occurs throughout the valley portions of the La Quinta area (note the distribution of Quaternary alluvium – Qal, interbedded Quaternary lake and alluvial deposits – Ql/Qal, and windblown sand – Qs, deposits, respectively, on Plate 2-1). The third condition – historically shallow groundwater within about 50 feet of the surface, has been reported in the eastern half of the General Plan area (DWR, 1964) both prior to the intense agricultural development of the region (in the early part of the 20th century), and again in the 1950s through 1970s, after the area started to rely significantly on imported Colorado River water. Due to the increasing development pressures of the 1980s and 1990s, pumping of water out of the underlying aquifers resulted in a significant lowering of the groundwater table. However, a shallow groundwater table could occur again in the future if water levels rise in response to decreased pumping of groundwater (due to increased use of imported water) and groundwater recharge.

The areas of La Quinta where young unconsolidated sediments and historically shallow groundwater conditions co-exist are shown on Plate 1-2 as susceptible to liquefaction. The eastern half of the General Plan area, where groundwater within 30 feet of the ground surface has been reported historically, is considered to have a high susceptibility to liquefaction, whereas areas with historical groundwater between about 30 and 50 feet below the ground surface are considered to have a moderate susceptibility to liquefaction. Geotechnical studies to evaluate the potential for liquefaction-induced differential settlement are recommended in these areas prior to development. Given that the groundwater levels in this area may fluctuate seasonally, the geotechnical analyses should use the shallowest groundwater levels reported in the area to calculate the anticipated settlement due to liquefaction.

Absent an official map from the California Geological Survey, Plate 1-2 should be used as if it were the official map, and site-specific liquefaction susceptibility studies should be conducted in the mapped areas prior to any proposed development. In accordance with the Seismic Hazards Mapping Act (SHMA), all projects within a State-delineated Seismic Hazard Zone for liquefaction must be evaluated by a Certified Engineering Geologist and/or Registered Civil Engineer (this is typically a civil engineer with training and experience in soil engineering). Most often however, it is appropriate for both the engineer and geologist to be involved in the evaluation, and in the implementation of the mitigation measures. Likewise, project review by the local agency must be performed by geologists and engineers with the same credentials and experience.

In order to assist project consultants and reviewers in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating liquefaction (CDMG, 1997; CGS, 2008). Furthermore, in 1999, a group sponsored by the Southern California Earthquake Center (SCEC, 1999) published recommended procedures for carrying out the California Geological Survey guidelines. More recently, a consensus report that describes new criteria for the definition and study of the liquefaction resistance of soils has been published by the Earthquake Engineering Research Center (Seed and others, 2003), and additional studies can be expected in this field. Consultants should review and apply the most recent, peer-reviewed guidelines for liquefaction study as applicable to the specific site being studied.

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

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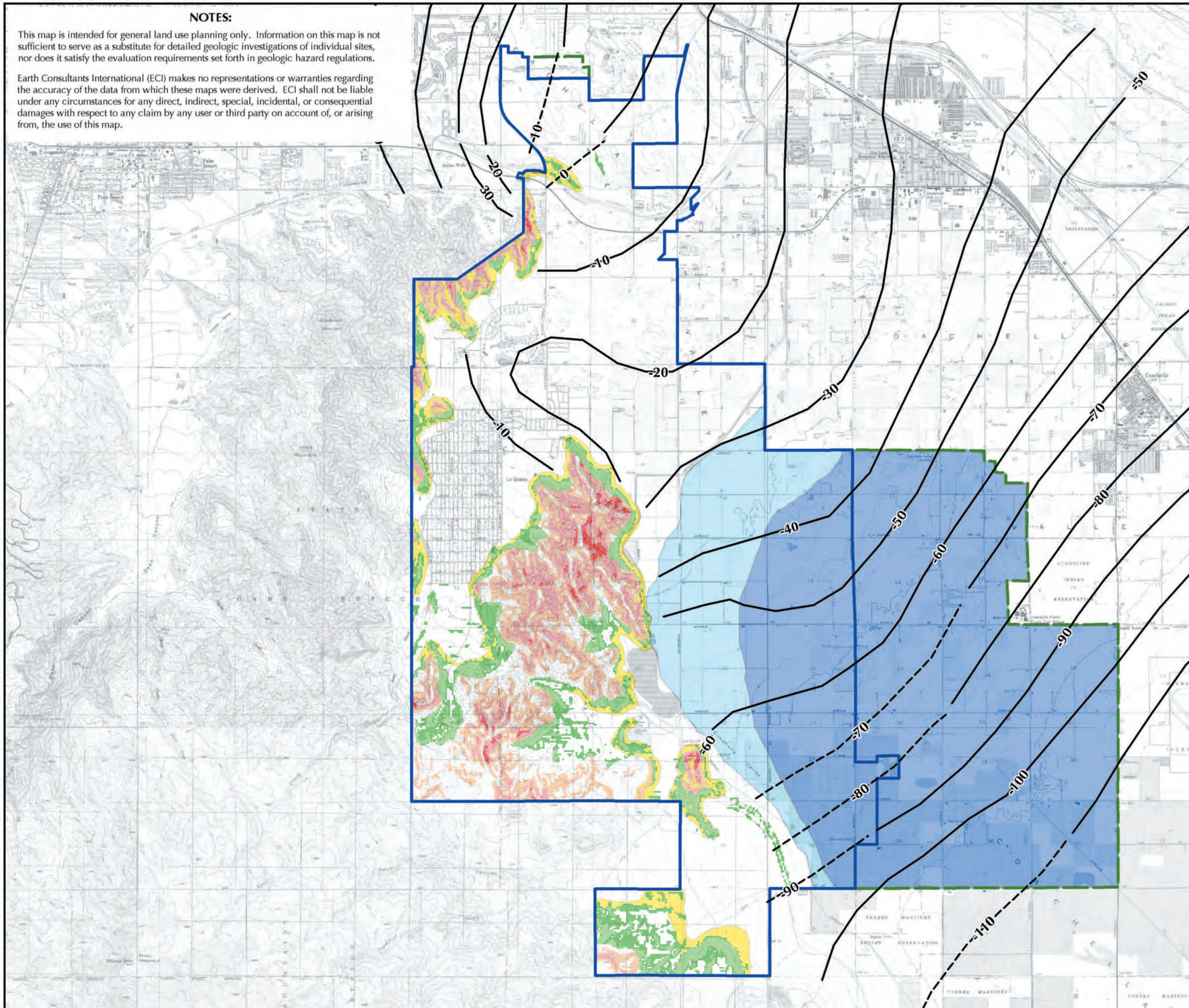

Seismic Hazards

La Quinta, California

Explanation

Earthquake-Induced Slope Instability

- Very High
- High
- Moderate
- Soil Block Slides
- Soil Slumps
- Rock Falls

Liquefaction Susceptibility

- High (areas underlain by youthful, unconsolidated sediments, and historically shallow groundwater within 30 feet of ground surface)
- Moderate (areas underlain by youthful, unconsolidated sediments, and historically shallow groundwater 30 to 50 feet below the ground surface)
- Groundwater Elevation per DWR 1964
- La Quinta City Boundary
- La Quinta Sphere of Influence

N W E S

6000 0 6000

Feet

2000 0 2000

Meters

Scale: 1:72,000

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Sources: Modified from Riverside County General Plan, Department of Water Resources Bulletin 108 (1964), and USGS 30m Digital Elevation Model

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Plate 1-2

In general, a liquefaction study is designed to identify the depth, thickness, and lateral extent of any liquefiable layers that would affect the project site. An analysis is then performed to estimate the type and amount of ground deformation that might occur, given the seismic potential of the area. Mitigation measures generally fall in one of two categories: ground improvement or foundation design. Ground improvement includes such measures as removal and recompaction of low-density soils, removal of excess ground water, in-situ ground densification, and other types of ground improvement (such as grouting or surcharging). Special foundations that may be recommended range from deep piles to reinforcement of shallow foundations (such as post-tensioned slabs). Mitigation for lateral spreading may also include modification of the site geometry or inclusion of retaining structures. The types (or combinations of types) of mitigation depend on the site conditions and on the nature of the proposed project (CDMG, 1997; CGS, 2008).

1.6.2 Earthquake-Induced Slope Failure

Strong ground motions can worsen existing unstable slope conditions. Seismically induced landslides can overrun structures, harm people or damage property, sever utility lines, and block roads, thereby hindering rescue operations after an earthquake. Over 11,000 landslides were mapped shortly after the 1994 Northridge earthquake, all within a 45-mile radius of the epicenter (Harp and Jibson, 1996). Although numerous types of earthquake-induced landslides have been identified, the most widespread type generally consists of shallow failures involving surficial soils and the uppermost weathered bedrock in moderate to steep hillside terrain (these are also called disrupted soil slides). Rockfalls and rock-slides on very steep slopes are also common. The 1989 Loma Prieta and 1994 Northridge earthquakes showed that reactivation of existing deep-seated landslides can also occur (Spittler and others, 1990; Barrows and others, 1995). One of the most impressive ancient landslides in the southern California region is the Martinez Mountain Landslide located immediately south of La Quinta (see Plate 2-2). Some geologists have suggested that seismic shaking triggered this rock avalanche (Morton and Saddler, 1989).

A combination of geologic conditions leads to landslide vulnerability. These include high seismic potential; rapid uplift and erosion resulting in steep slopes and deeply incised canyons; highly fractured and folded rock; and rock with inherently weak components, such as silt or clay layers. The orientation of the slope with respect to the direction of the seismic waves (which can affect the shaking intensity) can also control the occurrence of landslides. Groundwater conditions at the time of the earthquake also play an important role in the development of seismically induced slope failures. For instance, the 1906 San Francisco earthquake occurred in April, after a winter of exceptionally heavy rainfall, and produced many large landslides and mudflows, some of which were responsible for several deaths. The 1989 Loma Prieta earthquake however, occurred in October, during the third year of a drought, and slope failures were limited primarily to rockfalls and reactivation of older landslides that was manifested as ground cracking in the scarp areas but with very little movement (Griggs and others, 1991).

The mountains south of La Quinta have not been mapped as being located within a State-delineated Seismic Hazard Zone for seismically induced landsliding because this mapping program has not yet been funded for Riverside County. Topographically, the La Quinta General Plan area is bordered to the south and west by rugged mountains with steep canyon walls. Although the hills and mountains themselves are for the most part undeveloped, the developments and infrastructure at the foot of these mountains are susceptible to earthquake-induced rockfalls. The older, heavily developed area of La Quinta is surrounded on three sides by mountains composed of granitic rock. This rock type weathers to form large boulders that often perch precariously on the slopes, posing a rockfall hazard to areas adjacent to and below these slopes. Shallow, surficial failures could also impact the areas directly downslope. Rockfalls may happen suddenly and without warning, but are more likely to occur in response to earthquake-induced ground shaking, during periods of intense rainfall, or as a result of man's activities, such as grading and blasting. Wilson and Keefer (1985) reported that ground acceleration of at least 0.10g in steep terrain is necessary to induce earthquake-related rockfalls. Although exceeding this level of shaking does not guarantee that rockfalls will occur, this is certainly a concern in La Quinta given the high ground accelerations anticipated in the area when the southern San Andreas fault ruptures next.

Plate 1-2 shows those areas in the General Plan area where the combined topographic and bedrock conditions indicate the potential for earthquake-induced slope instability. Areas directly downhill from these mountainous regions are most vulnerable to the effects of slope failure. Existing slopes that are to remain adjacent to or within proposed developments should be evaluated for the geologic conditions mentioned above. For suspect slopes, appropriate geotechnical investigation and slope stability analyses should be performed for both static and dynamic (earthquake) conditions. Protection from rockfalls or surficial slides can often be achieved by protective devices such as barriers, retaining structures, catchment areas, or a combination of the above. The runout area of the slide at the base of the slope, and the potential bouncing of rocks must also be considered. If it is not feasible to mitigate the unstable slope conditions, building setbacks should be imposed.

In accordance with the SHMA, all development projects within a State-delineated Seismic Hazard Zone for seismically induced landsliding must be evaluated and reviewed by State-licensed engineering geologists and/or civil engineers (for landslide investigation and analysis, this typically requires both). In order to assist in the implementation of the SHMA, the State has published specific guidelines for evaluating and mitigating seismically induced landslides (CDMG, 1997; CGS, 2008). The Southern California Earthquake Center (SCEC, 2002) sponsored the publication of the "Recommended Procedures for Implementation of DMG Special Publication 117." The steep slope areas identified in Plates 1-2 and 2-2 should be evaluated following these procedures if development near these slopes is proposed.

1.6.3 Seismically Induced Settlement

Under certain conditions, strong ground shaking can cause the densification of soils, resulting in local or regional settlement of the ground surface. During strong shaking, soil grains become more tightly packed due to the collapse of voids and pore spaces, resulting in a reduction of the thickness of the soil column. This type of ground failure typically occurs in loose granular, cohesionless soils, and can occur in either wet or dry conditions. Unconsolidated young alluvial deposits are especially susceptible to this hazard. Artificial fills may also experience seismically induced settlement. Damage to structures typically occurs as a result of local differential settlements. Regional settlement can damage pipelines by changing the flow gradient on water and sewer lines, for example. As shown in Plate 2-1, certain areas of La Quinta are underlain by young, unconsolidated alluvial, lacustrine and wind deposits (map symbols Qa, Qa/Ql and Qs). These sediments are susceptible to seismically induced settlement.

Mitigation measures for seismically induced settlement are similar to those used for liquefaction. Recommendations are provided by the project's geologist and soil engineer, following a detailed geotechnical investigation of the site. Overexcavation and recompaction is the most commonly used method to densify soft soils susceptible to settlement. Deeper overexcavation below final grades, especially at cut/fill, fill/natural or alluvium/bedrock contacts may be recommended to provide a more uniform subgrade. Overexcavation should also be performed so that large differences in fill thickness are not present across individual lots. In some cases, specially designed deep foundations, strengthened foundations, and/or fill compaction to a minimum standard that is higher than that required by the UBC may be recommended.

1.6.4 Deformation of Sidehill Fills

Sidehill fills are artificial fill wedges typically constructed on natural slopes to create roadways or level building pads. Deformation of sidehill fills was noted in earlier earthquakes, but this phenomenon was particularly widespread during the 1994 Northridge earthquake. Older, poorly engineered road fills were most commonly affected, but in localized areas, building pads of all ages experienced deformation. The deformation was usually manifested as ground cracks at the cut/fill contacts, differential settlement in the fill wedge, and bulging of the slope face. The amount of displacement on the pads was generally about three inches or less, but this resulted in minor to severe property damage (Stewart and others, 1995). This phenomenon was most common in relatively thin fills (about 27 feet or less) placed near the tops or noses of narrow ridges (Barrows and others, 1995).

This hazard could occur locally in the hillsides and mountains of the La Quinta region, especially where service roads and foundation pads have been cut onto the side of a slope (such as for above-ground water tanks). Fills placed on the outside side of a cut so as to create a wider road or building pad are particularly vulnerable to deformation as a result of ground shaking.

Hillside grading designs are typically conducted during site-specific geotechnical investigations to determine if there is a potential for this hazard. There are currently no proven engineering standards for mitigating sidehill fill deformation, consequently current published research on this topic should be reviewed by project consultants at the time of their investigation. It is thought that the effects of this hazard on structures may be reduced by the use of post-tensioned foundations, deeper overexcavation below finish grades, deeper overexcavation on cut/fill transitions, and/or higher fill compaction criteria.

1.6.5 Ridgetop Fissuring and Shattering

Linear, fault-like fissures occurred on ridge crests in a relatively concentrated area of rugged terrain in the Santa Cruz Mountains during the 1989 Loma Prieta earthquake. Shattering of the surface soils on the crests of steep, narrow ridgelines occurred locally in the 1971 San Fernando earthquake, but was widespread in the 1994 Northridge earthquake. Ridgetop shattering (which leaves the surface looking as if it was plowed) by the Northridge earthquake was observed as far as 22 miles away from the epicenter. In the Sherman Oaks area, severe damage occurred locally to structures located at the tops of relatively high (greater than 100 feet), narrow (typically less than 300 feet wide) ridges flanked by slopes steeper than about 2.5:1 (horizontal:vertical). It is generally accepted that ridgetop fissuring and shattering is a result of intense amplification or focusing of seismic energy due to local topographic effects (Barrows and others, 1995).

Ridgetop shattering is likely to occur locally in the Santa Rosa and San Jacinto mountains within and bordering the La Quinta area during a strong earthquake on the San Andreas or San Jacinto faults. Given that there is none or very little development on these ridgelines, and that no future development is anticipated, damage to structures as a result of this hazard in the La Quinta area is anticipated to be low to none, with the exception of the several above-ground water storage tanks located at the top of ridgelines in the General Plan area. These tanks could experience strong ground shaking if the seismic energy is amplified along the ridges.

Projects located or proposed in steep hillside areas should be evaluated for this hazard by a Certified Engineering Geologist. Given that it is difficult to predict exactly where this hazard may occur, avoidance of development along the tops of steep, narrow ridgelines is probably the best mitigation measure. Recontouring of the topography to reduce the conditions conducive to ridgetop amplification, along with overexcavation below finish grades to remove and recompact weak, fractured bedrock is thought to reduce this hazard to an acceptable level.

1.7 Other Potential Seismic Hazards

1.7.1 Seiches

A seiche is defined as a standing wave oscillation in an enclosed or semi-enclosed, shallow to moderately shallow water body or basin. Seiches continue (in a pendulum fashion) after the cessation of the originating force, which can be tidal action, wind action, or a seismic event. Reservoirs, lakes, ponds, swimming pools and other enclosed bodies of water are subject to these potentially damaging oscillations (sloshing). Whether or not seismically induced seiches develop in a water body is dependent upon specific earthquake parameters (e.g., frequency of the seismic waves, distance and direction from the epicenter), as well as site-specific design of the enclosed bodies of water, and is thus difficult to predict. Whether an earthquake will create seiches depends upon a number of earthquake-specific parameters, including the earthquake location (a distant earthquake is more likely to generate a seiche than a local earthquake), the style of fault rupture (e.g., dip-slip or strike-slip), and on the configuration (length, width and depth) of the basin.

Amplitudes of seiche waves associated with earthquake ground motion are typically less than 0.5 m (1.6 feet high), although some have exceeded 2 m (6.6 ft). A seiche in Hebgen Reservoir, caused by an earthquake in 1959 near Yellowstone National Park, repeatedly overtopped the dam, causing considerable damage to the dam and its spillway (Stermitz, 1964). The 1964 Alaska earthquake produced seiche waves 0.3 m (1 ft) high in the Grand Coulee Dam reservoir, and seiches of similar magnitude were reported in fourteen bodies of water in the state of Washington (McGarr and Vorhis, 1968). Seiches in pools and ponds as a result of the 2010 Baja California earthquake were reported and often captured on video in southern California and Arizona, and the Chile earthquake of February 27, 2010 reportedly caused a 0.5-foot-high seiche 4,700 miles away in Lake Pontchartrain, New Orleans.

Given that there are several lakes, ponds, and reservoirs in and around La Quinta, seiches as a result of ground shaking can be expected to occur in the study area. Specifically, the enclosed bodies of water in La Quinta with the potential for seiching include Lake Cahuilla, as well as smaller golf course lakes, and the recharge basins south of Lake Cahuilla. The amplitude of the seiche waves that could occur in these water bodies cannot be predicted given that several parameters combine to form these waves. Thus, property owners down-gradient from ponds, lakes and pools that could seiche during an earthquake should be aware of the potential hazard to their property should any of these bodies of water lose substantial amounts of water during an earthquake. Water in swimming pools is known to slosh during earthquakes, but in most cases, the sloshing does not lead to significant damage.

Damage as a result of sloshing of water inside water reservoirs is discussed further in the Flood Hazards Chapter (Chapter 3). Site-specific design elements, such as baffles, to reduce the potential for seiches are warranted in tanks and in open reservoirs or ponds where overflow or failure of the structure may cause damage to nearby properties. Damage to water tanks in recent earthquakes, such as the 1992 Landers-Big Bear sequence and the 1994 Northridge, resulted from seiching. As a result of those earthquakes, the American Water Works Association (AWWA) developed Standards for Design of Steel Water Tanks (D-100) that provide revised criteria for seismic design (Lund, 1994).

1.7.2 Tsunami

A tsunami is a sea wave caused by any large-scale disturbance of the ocean floor that occurs in a short period of time and causes a sudden displacement of water. The most frequent causes of tsunamis are shallow underwater earthquakes and submarine landslides, but tsunamis can also be caused by underwater volcanic explosions, oceanic meteor impacts, and even underwater nuclear explosions. Tsunamis can travel across an entire ocean basin, or they can be local. Tsunamis are characterized by their length, speed, low period, and low observable amplitude: the waves can be up to 200 km (125 mi) long from one crest to the next, they travel in the deep ocean at speeds of up to 950 km/hr (600 mi/hr), and have periods of between 5 minutes and up to a few hours (with most tsunami periods ranging between 10 and 60 minutes). Their height in the open ocean is very small, a few meters at most, so they pass under ships and boats undetected (Garrison, 2002), but may pile up to heights of 30 m (100 ft) or more on entering shallow water along an exposed coast, where they can cause substantial damage. The highest elevation that the water reaches as it runs up on the land is referred to as wave runup, uprush, or inundation height (McCulloch, 1985; Synolakis et al., 2002). Inundation refers to the horizontal distance that a tsunami wave penetrates inland (Synolakis et al., 2002).

Because of the substantial increase in population in the last century and extensive development along the world's coastlines, a large percentage of the Earth's inhabitants live near the ocean. As a result, the risk of loss of life and property damage due to tsunami has increased substantially. Between 1992 and 2002, tsunamis were responsible for over 4,000 human deaths worldwide (Synolakis et al., 2002). Then, on December 26, 2004, a magnitude 9.3 earthquake off the northwest coast of Sumatra, Indonesia caused tsunamis in the Indian Ocean that resulted in more than 184,000 confirmed fatalities in the region, with another nearly 170,000 missing, and presumed killed, in Indonesia alone. The earthquake and resulting tsunamis also displaced nearly 1.7 million people in ten countries in South Asia and East Africa, making it the most devastating natural event in recorded history, and increasing overnight the worldwide awareness of tsunamis as a potentially devastating natural hazard. Hundreds of tourists that did not know about evacuating to higher ground were killed by the tsunamis. More recently, the September 29, 2009 earthquake and tsunami sequence in Samoa killed 189 people, and the February 27, 2010 earthquake in Chile also generated several tsunami waves. The damage from the 2010 Chilean tsunami has not been tallied yet.

Given La Quinta's inland location, the tsunami hazard in the city is nil.

1.8 Vulnerability of Structures to Earthquake Damage

Although it is not possible to prevent earthquakes from occurring, their destructive effects can be minimized, especially since most of the loss of life and injuries due to an earthquake are related to the collapse of hazardous buildings and structures. [FEMA (1985) defines a hazardous building as "any inadequately earthquake resistant building, located in a seismically active area, that presents a potential for life loss or serious injury when a damaging earthquake occurs."] Therefore, the vulnerability of a community to earthquake damage can be reduced with a comprehensive hazard mitigation program that includes the identification and mapping of hazards, prudent planning and enforcement of building codes, and expedient retrofitting and rehabilitation of weak structures.

As discussed previously, building codes have generally been made more stringent following damaging earthquakes. To mitigate for seismic shaking in new construction, recent building codes use amplification factors to account for the impacts that soft sediments and proximity to earthquake sources have on ground motion. Three main effects are considered: (1) soft soils, (2) proximity to earthquake sources (referred to as near-source factors), and (3) the seismic characteristics of the nearby earthquake sources (seismic source type). Each of these effects is discussed further below.

Soft-Soil Effects – The soft soil amplification factors were developed from observations made after the 1985 Mexico City, 1989 Loma Prieta and other earthquakes that showed the amplifying impact that underlying soil materials have on ground shaking. The ground-shaking basis for code design includes six soil types based on the average soil properties for the top 100 feet of the soil profile (see Plate 1-3).

Youthful, unconsolidated alluvial sediments classified as site class type E soils may underlie those portions of the La Quinta General Plan area that are susceptible to liquefaction (refer to Plate 1-3). The lacustrine deposits (see Plate 2-1) may locally contain clay layers thick enough to be described as site class E. Site-specific studies need to be conducted in these areas to determine whether these soils fall within site class type E or D. Other areas of the valley underlain by youthful, unconsolidated sediments, but where groundwater is too deep for liquefaction to occur are best represented by site class D. The older alluvial fan sediments at the base of the mountains, in the southern part of the General Plan area, are best represented by site class C, except that these deposits are expected to be significantly less than 100 feet thick, and underlain by hard bedrock. For this reason, site class A or B may be most appropriate for these areas. Site-specific studies designed to characterize the shear wave velocity and undrained shear strength of the soil column would be necessary if these fans were to be developed. However, development of these surfaces is not anticipated.

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

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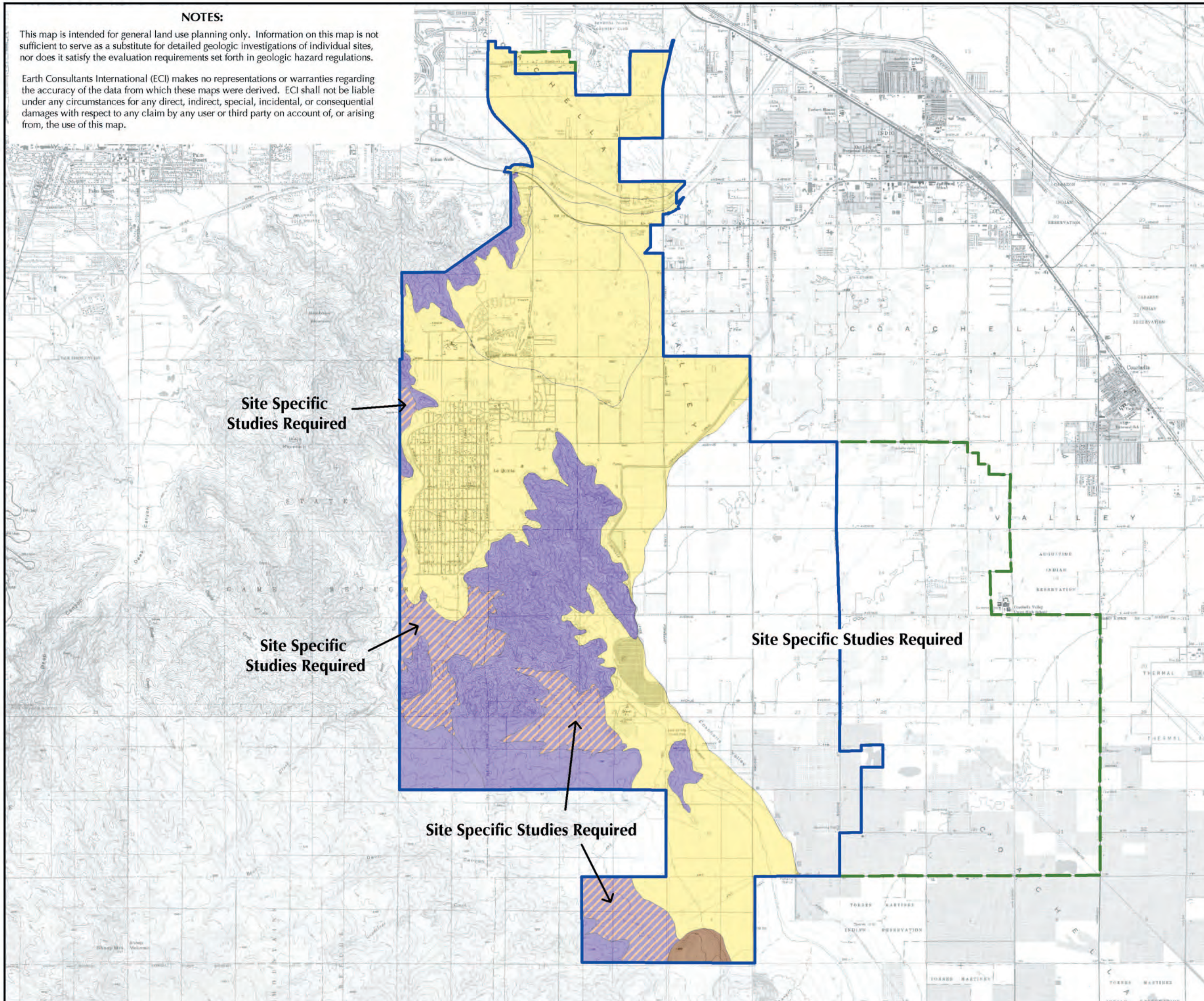

Engineering Site Classes

La Quinta, California

(Based on Soil Profile Types per CBC, 2007)

Symbols

City of La Quinta City Boundary

La Quinta Sphere of Influence

For Site Class Descriptions and Properties See Plate 1-3b

N

W E

S

6000 0 6000

Feet

2000 0 2000

Meters

Scale: 1:72,000

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997.
Sources: Based on data from Dibblee, 2008 and CBC, 2007.

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Plate 1-3a

Symbols

La Quinta City Boundary

La Quinta Sphere of Influence

Site Class Definitions (Based on Soil Profile Types) (from CBC, 2007)

Site Class	Soil Profile Name/Generic Description	Average Soil Properties for the Upper 100 feet		
		Shear Wave Velocity (feet/second)	**Standard Penetration Resistance (blows/foot)**	**Undrained Shear Strength (psf)**
A	Hard Rock	>5,000	N/A	N/A
B	Rock	2,500 to 5,000	N/A	N/A
C	Very dense soil and soft rock	1,200 to 2,500	>50	>2,000
D	Stiff soil profile	600 to 1,200	15 to 50	1,000 to 2,000
E	Soft soil profile	<600	<15	<1,000
	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index PI > 20 2. Moisture Content w>= 40%, and 3. Undrained shear strength < 500 psf			
F	Any profile containing soil having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays, where the thickness of this section is more than 10 feet. 3. Very high plasticity clays (more than 25 feet of clay with plasticity index PI > 75). 4. Very thick soft/medium stiff clays (thickness of the soil > 120 feet).			

From Table 1613.5.2 of the 2007 California Building Code
psf = pounds per square foot

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Explanation for Engineering Site Classes

Plate 1-3b

Near- Source Factors – The La Quinta area is subject to near-source design factors given that the San Andreas fault is within 15 km of the city (see Table 1-2 and Plate 1-1). These parameters, which first appeared in the 1997 Uniform Building Code (UBC), address the proximity of potential earthquake sources (faults) to the site. These factors were present in earlier versions of the UBC for implementation into the design of seismically isolated structures, but are now included for all structures. The adoption into the 1997 code of all buildings in UBC seismic zone 4 is the result of observations of intense ground shaking at levels higher than expected near the fault ruptures at Northridge in 1994, and again one year later, in Kobe, Japan. The 1997 UBC also included a near-source factor that accounts for directivity of fault rupture. The direction of fault rupture was observed to play a significant role in distribution of ground shaking at Northridge and Kobe. For Northridge, much of the earthquake energy was released into the sparsely populated mountains north of the San Fernando Valley, while at Kobe, the rupture direction was aimed at the city and was a contributing factor in the extensive damage. However, the rupture direction of a given source cannot be predicted, and as a result, the UBC required a general increase in estimating ground shaking of about 20% to account for directivity.

Seismic Source Type – Near-source factors also include a classification of seismic sources based on slip rate and maximum magnitude potential. These parameters are used in the classification of three seismic source types (A, B and C) summarized on Table 1-3.

Table 1-3: Seismic Source Type

Seismic Source Type	Seismic Source Description	Seismic Source Definition	
		Maximum Moment Magnitude, M	Slip Rate, SR (mm/yr.)
A	Faults which are capable of producing large magnitude events and which have a high rate of seismicity.	$M \geq 7.0$ and	$SR \geq 5$
B	All faults other than Types A and C.		
C	Faults which are not capable of producing large magnitude earthquakes and which have a relatively low rate of seismic activity.	$M < 6.5$	$SR \leq 2$

Type A faults are highly active and capable of producing large magnitude events. Most segments of the San Andreas fault, for example, are classified as Type A. The Type A slip rate (>5 mm/yr) is common only to tectonic plate boundary faults. Type C seismic sources are considered not capable of producing large magnitude events such that their potential ground shaking effects can be ignored. Type B sources include most of the active faults in California and include all faults that are neither Type A nor C. The Type A faults closest to La Quinta are the San Andreas and San Jacinto faults. Type B faults in the region include the Burnt Mountain, Eureka Peak, Pinto Mountain, Pisgah-Bullion, and all the faults in the Mojave (or Eastern California) Shear Zone (see Table 1-2) (Cao and others, 2003). To establish near-source factors for any proposed project in the city of La Quinta, one has to determine the shortest distance between the project and the nearest active trace of the San Andreas fault.

Building damage is commonly classified as either structural or non-structural. Structural damage impairs the building's support. This includes any vertical and lateral force-resisting systems, such as frames, walls, and columns. Non-structural damage does not affect the integrity of the structural support system, but includes such things as broken windows, collapsed or rotated chimneys, unbraced parapets that fall into the street, and fallen ceilings.

During an earthquake, buildings get thrown from side to side and up and down. Given the same acceleration, heavier buildings are subjected to higher forces than lightweight buildings. Damage occurs when structural members are overloaded, or when differential movements between different parts of the structure strain the structural components. Larger earthquakes and longer shaking duration tend to damage structures more. The level of damage can be predicted only in general terms, since no two buildings undergo the exact same motions, even in the same earthquake. Past earthquakes have shown, however, that some types of buildings are far more likely to fail than others. This section assesses the general earthquake vulnerability of structures and facilities common in the southern California area, including in La Quinta. This analysis is based on past earthquake performance of similar types of buildings in the U.S. The effects of design earthquakes on particular structures within La Quinta are beyond the scope of this study.

1.8.1 Unreinforced Masonry Buildings

Unreinforced masonry buildings (URMs) are prone to failure due to inadequate anchorage of the masonry walls to the roof and floor diaphragms, lack of steel reinforcing, the limited strength and ductility of the building materials, and sometimes, poor construction workmanship. Furthermore, as these buildings age, the bricks and mortar tend to deteriorate, making the buildings even weaker. As a result, the State Legislature passed Senate Bill 547, addressing the identification and seismic upgrade of URMs.

In response to the URM Law, all cities and counties in what the Building Code in effect at the time referred as Seismic Zone 4 were to conduct an inventory of their URMs, establish an URM loss-reduction program, and report their progress to the State by 1990. The Seismic Safety Commission has conducted updates to this inventory, more recently in 2003 and 2006.

In 2006, the City of La Quinta reported to the Seismic Safety Commission that there were seven URMs in the city. Five of these had been retrofitted and thus are no longer classified as unreinforced, one was slated for demolition, and there were no mitigation plans on file for the seventh and final one. As part of this report, personnel from the City's Building Department have indicated that the last two unmitigated URMs in La Quinta still exist, but they are vacant and not being used. Both buildings, which are of adobe construction, are in the grounds of the La Quinta Resort.

1.8.2 Soft-Story Buildings

Of particular concern are soft-story buildings (buildings with a story, generally the first floor, lacking adequate strength or toughness due to too few shear walls). Residential units above glass-fronted stores, and buildings perched atop parking garages are common examples of soft-story buildings. Collapse of a soft story and "pancaking" of the remaining stories killed 16 people at the Northridge Meadows apartments during the 1994 Northridge earthquake (EERI, 1995). There are many other cases of soft-story collapses in past earthquakes. In response, the State encourages the identification and mitigation of seismic hazards associated with these types of potentially hazardous buildings, and others such as pre-1971 concrete tilt-ups, mobile homes, and pre-1940 homes. The City of La Quinta should consider conducting an inventory of their soft-stories, and encouraging the structural retrofit of these structures so that they not collapse during an earthquake.

1.8.3 Wood-Frame Structures

The loss estimations conducted for this study (see Section 1.9) indicates that nearly 61% of wood-frame structures in La Quinta are expected to experience slight to complete damage as a result of ground shaking caused by an earthquake on the San Andreas fault, with about 10% experiencing moderate to complete damage. An earthquake on the Anza segment of the San Jacinto fault is anticipated to cause at least slight damage to about 25% of the wood-frame structures in the La Quinta area.

Structural damage to wood-frame structures often results from an inadequate connection between the superstructure and the foundation. These buildings may slide off their foundations, with consequent damage to plumbing and electrical connections. Unreinforced masonry chimneys may also collapse. These types of damage are generally not life threatening, although they may be costly to repair. Wood frame buildings with stud walls generally perform well during an earthquake, unless they have no foundation or have a weak foundation constructed of unreinforced masonry or poorly reinforced concrete. In these cases, damage is generally limited to cracking of the stucco, which dissipates much of the earthquake's induced energy. The collapse of wood frame structures, if it happens, generally does not generate heavy debris, but rather, the wood and plaster debris can be cut or broken into smaller pieces by hand-held equipment and removed by hand in order to reach victims (FEMA, 1985).

1.8.4 Pre-Cast Concrete Structures

Partial or total collapse of buildings where the floors, walls and roofs fail as large intact units, such as large pre-cast concrete panels, cause the greatest loss of life and difficulty in victim rescue and extrication (FEMA, 1985). These types of buildings are common not only in southern California, but abroad. Casualties as a result of collapse of these structures in past earthquakes, including Mexico (1985), Armenia (1988), Nicaragua (1972), El Salvador (1986 and 2001), the Philippines (1990), Turkey (1999) and China (2008) add to hundreds of thousands. In southern California, many of the parking structures that failed during the Northridge earthquake, such as the Cal-State Northridge and City of Glendale Civic Center parking structures, consisted of pre-cast concrete components (EERI, 1995).

Collapse of this type of structure generates heavy debris, and removal of this debris requires the use of heavy mechanical equipment. Consequently, the location and extrication of victims trapped under the rubble is generally a slow and dangerous process. Extrication of trapped victims within the first 24 hours after the earthquake becomes critical for survival. In most instances, however, post-earthquake planning fails to quickly procure the equipment needed to move heavy debris. The establishment of Heavy Urban Search and Rescue teams, as recommended by FEMA (1985), has improved victim extrication and survivability. Buildings that are more likely to fail and generate heavy debris need to be identified, so that appropriate mitigation and planning procedures are defined prior to an earthquake.

1.8.5 Tilt-up Buildings

Tilt-up buildings have concrete wall panels, often cast on the ground, or fabricated off-site and trucked in, which are then tilted upward into their final position. Connections and anchors have pulled out of walls during earthquakes, causing the floors or roofs to collapse. A high rate of failure was observed for this type of construction in the 1971 San Fernando and 1987 Whittier Narrows earthquakes. Tilt-up buildings can also generate heavy debris.

1.8.6 Reinforced Concrete Frame Buildings

Reinforced concrete frame buildings, with or without reinforced infill walls, display low ductility. Earthquakes may cause shear failure (if there are large tie spacings in columns, or insufficient shear strength), column failure (due to inadequate rebar splices, inadequate reinforcing of beam-column joints, or insufficient tie anchorage), hinge deformation (due to lack of continuous beam reinforcement), and non-structural damage (due to the relatively low stiffness of the frame). A common type of failure observed following the Northridge earthquake was confined column collapse (EERI, 1995), where infilling between columns confined the length of the columns that could move laterally in the earthquake.

1.8.7 Multi-Story Steel Frame Buildings

Multi-story steel frame buildings generally have concrete floor slabs. However, these buildings are less likely to collapse than concrete structures. Common damage to these types of buildings is generally non-structural, including collapsed exterior curtain wall (cladding), and damage to interior partitions and equipment. Overall, modern steel frame buildings have been expected to perform well in earthquakes, but the 1994 Northridge earthquake broke many welds in these buildings, a previously unanticipated problem.

Older, pre-1945 steel frame structures may have unreinforced masonry such as bricks, clay tiles and terra cotta tiles as cladding or infilling. Cladding in newer buildings may be glass, infill panels or pre-cast panels that may fail and generate a band of debris around the building exterior (with considerable threat to pedestrians in the streets below). Structural damage may occur if the structural members are subject to plastic deformation, which can cause permanent displacements. If some walls fail while others remain intact, torsion or soft-story problems may result.

1.8.8 Mobile Homes

Mobile homes are prefabricated housing units that are placed on isolated piers, jackstands, or masonry block foundations (usually without any positive anchorage). Floors and roofs of mobile homes are usually plywood, and outside surfaces are covered with sheet metal. Mobile homes typically do not perform well in earthquakes. Severe damage occurs when they fall off their supports, severing utility lines and piercing the floor with jackstands. The results of the loss estimation analyses indicate that more than 95% of the mobile homes in La Quinta area are likely to experience moderate to complete damage as a result of an earthquake on the San Andreas fault, and almost 100% will experience some damage, from slight to complete. An earthquake on the more distant San Jacinto fault is anticipated to cause at least slight damage to about 59% of the mobile homes in the area. This indicates that the seismic hazard in the La Quinta can be mitigated to some extent if manufactured homes in the city are inspected and seismically retrofitted as needed.

1.8.9 Combination Types

Buildings are often a combination of steel, concrete, reinforced masonry and wood, with different structural systems on different floors or different sections of the building. Combination types that are potentially hazardous include: concrete frame buildings without special reinforcing, precast concrete and precast-composite buildings, steel frame or concrete frame buildings with unreinforced masonry walls, reinforced concrete wall buildings with no special detailing or reinforcement, large capacity buildings with long-span roof structures (such as theaters and auditoriums), large un-engineered wood-frame buildings, buildings with inadequately anchored exterior cladding and glazing, and buildings with poorly anchored parapets and appendages (FEMA, 1985). Additional types of potentially hazardous buildings may be recognized after future earthquakes.

In addition to building types, there are other factors associated with the design and construction of the buildings that also have an impact on the structures' vulnerability to strong ground shaking. Some of these conditions are discussed below:

Building Shape – A building's vertical and/or horizontal shape can also be important in determining its seismic vulnerability. Simple, symmetric buildings generally perform better than non-symmetric buildings. During an earthquake, non-symmetric buildings tend to twist, as well as shake. Wings on a building tend to act independently during an earthquake, resulting in differential movements and cracking. The geometry of the lateral load-resisting systems also matters. For example, buildings with one or two walls made mostly of glass, while the remaining walls are made of concrete or brick, are at risk. Asymmetry in the placement of bracing systems that provide a building with earthquake resistance can result in twisting or differential motions.

Pounding – Site-related seismic hazards may include the potential for neighboring buildings to "pound," or for one building to collapse onto a neighbor. Pounding occurs when there is little clearance between adjacent buildings, and the buildings "pound" against each other as they deflect during an earthquake. The effects of pounding can be especially damaging if the floors of the buildings are at different elevations, so that, for example, the floor of one building hits a supporting column of the other. Damage to a supporting column can result in partial or total building collapse.

1.9 Earthquake Scenarios and Loss Estimations

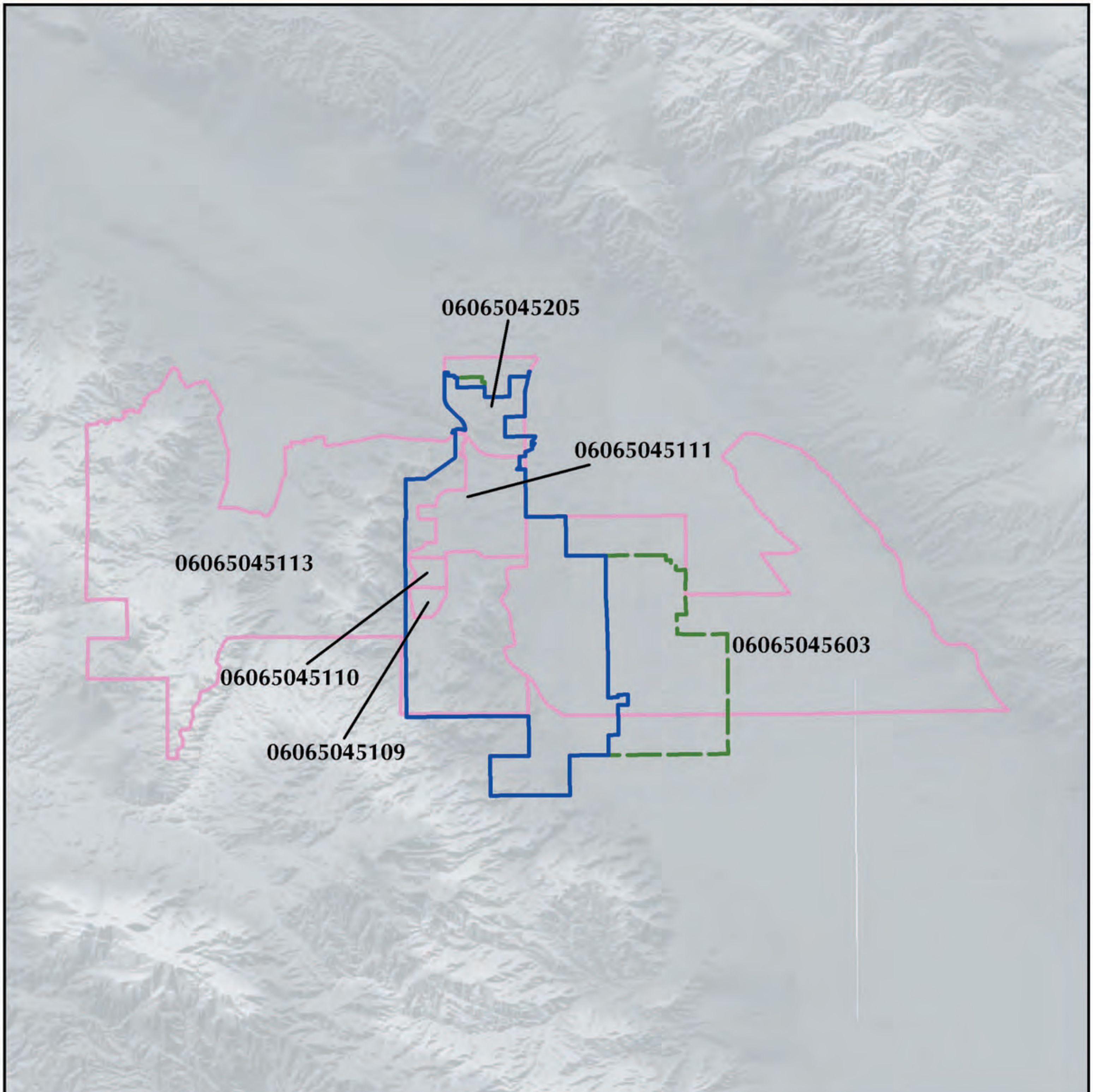
HazUS-MH™ is a standardized methodology for earthquake loss estimation based on a geographic information system (GIS). [HazUS-MH stands for Hazards United States – Multi-hazard.] A project of the National Institute of Building Sciences, funded by the Federal Emergency Management Agency (FEMA), HazUS is a powerful advance in mitigation strategies. The HazUS project developed guidelines and procedures to make standardized earthquake loss estimates at a regional scale. With standardization, estimates can be compared from region to region. HazUS is designed for use by state, regional and local governments in planning for earthquake loss mitigation, and emergency preparedness, response and recovery. HazUS addresses nearly all aspects of the built environment, and many different types of losses. The methodology has been tested against the experience of several past earthquakes, and against the judgment of experts.

Subject to several limitations noted below, HazUS can produce results that are valid for the intended purposes.

Loss estimation is an invaluable tool, but it must be used with discretion. Loss estimation analyzes casualties, damage and economic loss in great detail. It produces seemingly precise numbers that can be easily misinterpreted. Loss estimation results, for example, may cite 454 left homeless by a scenario earthquake. This is best interpreted by its magnitude. That is, an event that leaves 400 people homeless is clearly more manageable than an event causing 4,000 homeless people; and an event that leaves 40,000 homeless will most likely overwhelm the region's resources. However, another loss estimation analysis that predicts 500 people homeless should be considered equivalent to the 454 result. Because HazUS results make use of a great number of parameters and data of varying accuracy and completeness, it is not possible to assign quantitative error bars. Although the numbers should not be taken at face value, they are not rounded or edited because detailed evaluation of individual components of the disaster can help mitigation agencies ensure that they have considered all the important variables.

The more community-specific the data that are input to HazUS, the more reliable the loss estimation. HazUS provides defaults for all required information. These are based on best-available scientific, engineering, census and economic knowledge. The loss estimations in this report have been tailored to the La Quinta General Plan area by including the more recent Riverside County HazUS data obtained as part of a project that developed a more detailed inventory of structures and essential facilities for Riverside, San Bernardino and Orange counties (H. Seligson and MMI Engineering, 2008). The revised inventory includes structure-specific information, including structural type, age and thus seismic design level (e.g., high, moderate, low, or pre-code), height, occupancy, and building replacement cost, among other variables, as provided by the owners of the structures. The HazUS analyses presented here also considered the soil types that underlie the city, and modifications to the population count, as described further below.

HazUS relies on census data, which are reported by geographical areas or tracts. Unfortunately, census tracts often do not correlate well with city boundaries, especially in areas with low population densities. This is certainly the case for La Quinta, where six census tracts cover the General Plan area but extend farther beyond, for a total area of almost 120 square miles (see Figure 1-6). Population counts were modified from those provided in the HazUS database (that date to the census of 2000) to acknowledge the significant growth that this area has experienced in the last decade. Essentially, the 2000 census data indicated a population of nearly 37,000 in the HazUS study region. This figure significantly under-represents the current population in the area, as the California Department of Finance estimates that the population within City of La Quinta boundaries on January 1, 2009 was 43,830, with another 41,043 people in neighboring Coachella (http://www.dof.ca.gov/research/demographic/reports/estimates/e-1/2009-10/), part of which is included in census tract No. 06065045603 (see Figure 1-6). For the purposes of this study, we estimated a population of 62,176 for the HazUS study area considered. This number was reached by multiplying the 2000 population count in each of the six census tracts in the region by a factor that represents our estimate of the growth in that census tract, as determined from a semi-quantitative count of new structures obtained from Google Earth images of the region dating from 1996, 2002 and 2010. In census tract 06065045603, we considered only the growth within the city of La Quinta and its Sphere of Influence, to limit the impact that the city of Coachella population counts could have on the results of the analysis.



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Feet
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Meters

Scale: 1:216,000

Explanation

Census Tract used in the HazUS analyses for La Quinta

La Quinta City Limit

La Quinta Sphere of Influence

Earth Consultants International

Project Number: 3004
Date: 2010

Census Tract Boundaries

Used in HazUS Analyses

Figure 1-6

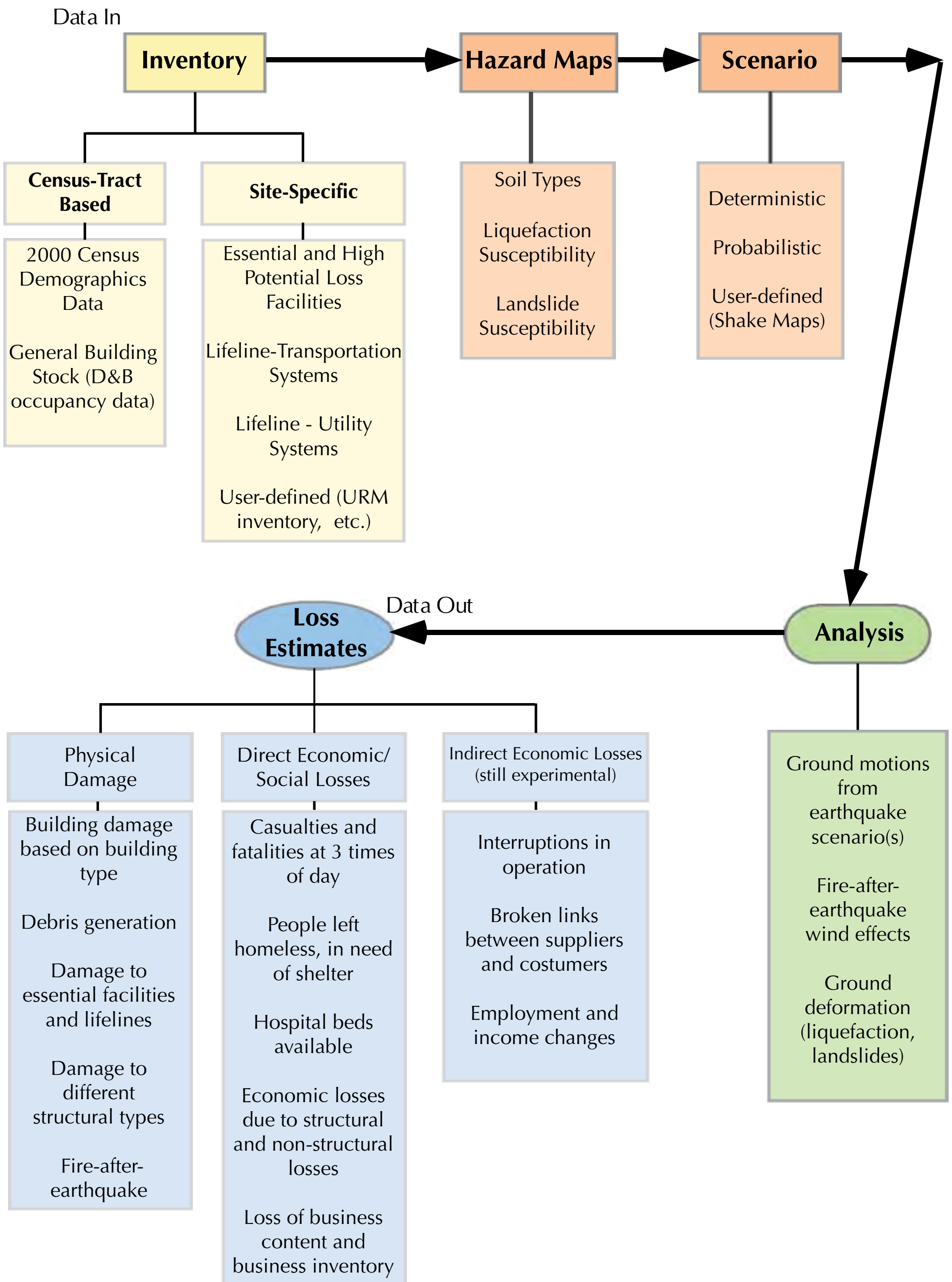
To estimate the number of households in the region, we divided the revised population counts by the average number of people per household in each census tract using the 2000 census numbers as a base, or by 2.8 (the average number of people per household reported for La Quinta). The number of households used in the analysis was 20,789.

As useful as HazUS can be, the loss estimation methodology has some inherent uncertainties. These arise, in part, from incomplete scientific knowledge concerning earthquakes and their effect upon buildings and facilities, and from the approximations and simplifications necessary for comprehensive analyses. Users should be aware of the following specific limitations:

- HazUS is driven by statistics, and thus is most accurate when applied to a region, or a class of buildings or facilities. It is least accurate when considering a particular site, building or facility.
- Losses estimated for lifelines may be less than losses estimated for the general building stock.
- Losses from smaller (less than M 6) earthquakes may be overestimated.
- Pilot and calibration studies have not yet provided an adequate test concerning the possible extent and effects of landsliding.
- The indirect economic loss module is still experimental. While output from pilot studies has generally been credible, this module requires further testing.
- The databases that HazUS draws from to make its estimates are often incomplete or as mentioned above, either do not match the boundaries of the desired study area, or are no longer representative of current conditions. In the case of La Quinta, and as explained above, we made adjustments to the population counts in the HazUS database to approximate the current population numbers.

Essential facilities and lifeline inventory are located by latitude and longitude. However, the HazUS inventory data for lifelines and utilities were developed at a national level and where specific data are lacking, statistical estimations are utilized. Specifics about the site-specific inventory data used in the models are discussed further in the paragraphs below. Other site-specific data used include soil types. The user then defines the earthquake scenario to be modeled, including the magnitude of the earthquake, and the location of the epicenter. Once all these data are input, the software calculates the loss estimates for each scenario (see Figure 1-7).

The loss estimates include physical damage to buildings of different construction and occupancy types, damage to essential facilities and lifelines, number of after-earthquake fires and damage due to fire. The model also estimates the direct economic and social losses, including casualties and fatalities for three different times of the day, the number of people left homeless and number of people that will require shelter, number of hospital beds available, and the economic losses due to damage to the places of businesses, loss of inventory, and (to some degree) loss of jobs. The indirect economic losses component is still experimental; the calculations in the software are checked against actual past earthquakes, such as the 1989 Loma Prieta and 1994 Northridge earthquakes, but indirect losses are hard to measure, and it typically takes years before these monetary losses can be quantified with any degree of accuracy.



Earth Consultants International

Project Number: 3004
Date: 2010

Generalized Flow Chart Summarizing the HazUS Methodology

Figure 1-7

Two specific earthquake scenarios were modeled: an earthquake on the southern San Andreas fault rupturing the Mojave, San Bernardino and Coachella Valley segments of the fault (the ShakeOut scenario prepared by the U.S. Geological Survey in the fall of 2008 – see the ShakeMap for this scenario in Figure 1-4), and an earthquake on the Anza segment of the San Jacinto fault originating at the segment's mid-point, approximately 20 miles to the southwest of La Quinta, and rupturing bilaterally to the north and south. Specifics about each of these earthquake-producing faults were provided in Sections 1.4.1 and 1.4.2 above, and in Table 1-4 below.

Table 1-4: HazUS Earthquake Scenarios for the City of La Quinta

Fault Source	Magnitude	Description
Southern San Andreas Fault	7.8	A large earthquake that ruptures the entire southern San Andreas fault using the U.S. Geological Survey's ShakeOut scenario. This earthquake has a high probability of occurrence, and it would be the worst-case scenario for the city of La Quinta.
Anza segment of San Jacinto Fault	7.2	Lower risk but relatively high probability earthquake event. The San Jacinto fault has generated the largest number of historical earthquakes in southern California. The Anza segment is the section of the fault closest to La Quinta.

The results indicate that of the two earthquake scenarios modeled for the city, the M_w 7.8 earthquake on the San Andreas fault will cause far more damage in La Quinta than a smaller earthquake on the more distant San Jacinto fault. For most of southern California, an earthquake on the San Andreas fault is not the worst-case scenario, as there are often other faults much closer that have the potential to be equally or more damaging. However, the San Andreas fault is the worst-case scenario for La Quinta and other communities in the Coachella and Imperial valleys – the fault's location and high probability of rupturing in the next 30 years resolve into a high probability, high risk seismic source for this region.

The following sections describe the specific losses anticipated in La Quinta due to the two earthquake scenarios modeled.

1.9.1 Building Damage

HazUS provides damage data for buildings based on these structural types:

- Concrete
- Manufactured Housing (Trailers and Mobile Homes)
- Precast Concrete
- Reinforced Masonry Bearing Walls
- Steel
- Unreinforced Masonry Bearing Walls
- Wood Frame

and based on these occupancy (usage) classifications:

- Agricultural

- Commercial
- Education
- Government
- Industrial
- Other Residential
- Religion
- Single Family

Loss estimation for the general building stock is averaged for each census tract. Building damage classifications range from slight to complete. As an example, the building damage classification for light, wood frame buildings, the most numerous building type in the city, is provided below.

- <u>Slight Structural Damage</u>: Small cracks in the plaster or gypsum-board at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.
- <u>Moderate Structural Damage</u>: Large cracks in the plaster or gypsum-board at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.
- <u>Extensive Structural Damage</u>: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of "room-over-garage" or other "soft-story" configurations; small foundation cracks.
- <u>Complete Structural Damage</u>: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or failure of the lateral load resisting system; some structures may slip and fall off their foundations; or develop large foundation cracks.

The HazUS database includes about 22,000 buildings in the region, with a total building replacement value (excluding contents) of $7,851 million. Approximately 91% of the buildings considered in the analysis (and 89% of the building value) are associated with residential housing. In terms of building construction types found in the region, wood-frame construction makes up approximately 83% of the building inventory, and manufactured housing comprises another 9%. The remaining about 8% is distributed between the other general building types.

Estimates of building damage are provided for "High," "Moderate" and "Low" seismic design criteria. Buildings of newer construction (e.g., post-1973) are best designated by "high." Buildings built after 1940, but before 1973, are best represented by "moderate" criteria. If built before about 1940 (i.e., before significant seismic codes were implemented), "low" is most appropriate. The building inventory for the six census tracts considered indicates that about 0.3% of the housing units were built before 1940. About 3.5% of the building units were built between 1940 and 1969; and more than 87% of the units were built after 1980. The remaining units (about 8.7%) were built in the decade between 1970 and 1979. Therefore, most of the housing stock in La Quinta can be described as in the "high" category for seismic design criteria. However, structural engineers point out that buildings constructed before building codes were upgraded following the 1994 Northridge earthquake have significant deficiencies that could result in higher-than-expected levels of damage. Specifically, in the 1980s, low-rise wood-frame construction relied on stucco and gypsum wallboard for shear resistance, but these materials were observed to perform poorly during the Northridge earthquake. As a result, the newer building codes reduced the shear forces permitted in these materials, and promoted an increase reliance on plywood-sheathed shear panels instead (Graf, 2008).

The HazUS models estimate that between 5,010 and 1,623 buildings in the La Quinta HazUS study area will be at least moderately damaged by the earthquake scenarios presented herein, with the higher number representative of damage as a result of an earthquake on the San Andreas fault, and the lower number representing damage as a result of an earthquake on the San Jacinto fault. These figures represent about 22% and 7%, respectively, of the total number of buildings in the region considered in the analysis. Table 1-5 summarizes the expected damage to buildings by general occupancy type, whereas Table 1-6 summarizes the expected damage to buildings in the region, classified by construction type.

Table 1-5: Number of Buildings* Damaged, by Occupancy Type

Scenario	Occupancy Type	Slight	Moderate	Extensive	Complete	Total
San Andreas	Agriculture	185	120	58	166	529
	Commercial	211	202	94	152	659
	Education	124	76	31	74	305
	Government	1	1	1	1	4
	Industrial	45	49	23	39	156
	Other Residential	471	558	288	1,288	2,605
	Religion	8	5	3	7	23
	Single Family	8,767	1,729	44	1	10,541
	Total	**9,812**	**2,740**	**542**	**1,728**	**14,822**
San Jacinto	Agriculture	108	55	12	2	177
	Commercial	155	98	21	2	276
	Education	64	27	4	0	95
	Government	1	1	0	0	2
	Industrial	37	25	6	1	69
	Other Residential	690	552	163	19	1,424
	Religion	5	3	1	0	9
	Single Family	3,704	607	20	6	4,337
	Total	**4,764**	**1,368**	**227**	**30**	**6,389**

* Based on a total of 22,333 buildings in the region.

As a percentage of the building damage by occupancy type, the model estimates that more than 74% of the residential structures other than single-family homes (i.e., multi-family residential buildings, including duplexes, condominiums and apartments) will suffer at least moderate damage from an earthquake on the San Andreas fault. Nearly 59% of the industrial structures, 58% of the agricultural, and 54% of the commercial structures in the La Quinta General Plan area will be at least moderately damaged by an earthquake on the San Andreas fault. Similarly, about 48% of the education buildings, 59% of the government buildings, and nearly 51% of the religion buildings will suffer at least moderate damage. A large-magnitude earthquake on the Anza segment of the San Jacinto fault is expected to cause at least moderate damage to nearly 26% of the residential structures other than single-family, and at least moderate damage to about 17%, 11.7% and 14.6% of the industrial, agricultural, and commercial structures, respectively, in the HazUS study area. The San Jacinto fault earthquake scenario is also anticipated to cause at least moderate damage to about 8% of the educational buildings and to 20% of the government buildings in the region.

Table 1-6: Number of Buildings* Damaged, by Construction Type

Scenario	Structure Type	Slight	Moderate	Extensive	Complete	Total
San Andreas	Wood	9,336	1,841	38	24	11,239
	Steel	81	113	63	203	460
	Concrete	83	47	32	99	261
	Precast	57	88	46	42	233
	Reinforced Masonry	159	200	95	118	572
	Manufactured Housing	94	452	268	1,243	2,057
	Total	**9,812**	**2,740**	**542**	**1,728**	**14,822**
San Jacinto	Wood	3,933	642	20	6	4,601
	Steel	96	74	18	3	191
	Concrete	61	31	7	1	100
	Precast	49	36	7	1	93
	Reinforced Masonry	98	71	16	0	185
	Manufactured Housing	528	514	158	19	1,219
	Total	**4,765**	**1,367**	**228**	**30**	**6,389**

* Based on a total of 22,333 buildings in the region.

Although wood-frame buildings comprise the largest number of buildings in the area, and therefore one would expect that most of the buildings damaged would be wood-frame structures, the data show that the building type that will suffer the most damage is manufactured housing. In fact, wood-frame buildings, as a group, are expected to perform well during an earthquake. Case in point, the ShakeOut earthquake on the San Andreas fault is anticipated to cause at least moderate damage to 1,903 wood-frame buildings, comprising about 10% of the total number of wood-frame buildings in the region, and to 1,963 manufactured homes, equal to more than 95% of the total number of manufactured homes in the study area. Similarly, an earthquake on the San Jacinto fault is expected to cause at least moderate damage to less than 4% of the wood-frame buildings, but to more than 33% of the manufactured homes in the region. The other building types in La Quinta, by construction type, that are anticipated to suffer at least moderate damage as a result of an earthquake on the San Andreas fault include steel (75.5% will be at least moderately damaged), precast (67.1%), concrete (56.5%), and reinforced masonry (55.3%). An earthquake on the Anza segment of the San Jacinto fault is anticipated to cause at least moderate damage to 19% of the steel buildings in La Quinta, 16.8% of the precast buildings, 12.4% of the concrete buildings, and 11.7% of the reinforced masonry buildings.

1.9.2 Casualties

Casualties are estimated based on the observation that there is a strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. In smaller earthquakes, non-structural damage, (such as toppled bookshelves and broken windows) is typically responsible for most of the casualties. In severe earthquakes where there is a large number of collapses and partial collapses, there is a proportionately larger number of fatalities. Data regarding earthquake-related injuries are, however, not of the best quality, nor are they available for all building types. Available data often have insufficient information about the type of structure in which the casualties occurred and the casualty-generating mechanism. HazUS casualty estimates are based on the injury classification scale described in Table 1-7.

In addition, HazUS produces casualty estimates for three times of day:

- Earthquake striking at 2:00 A.M. (population at home)
- Earthquake striking at 2:00 P.M. (population at work/school)
- Earthquake striking at 5:00 P.M. (commute time).

Table 1-7: Injury Classification Scale

Injury Severity Level	Injury Description
Severity 1	Injuries requiring basic medical aid without requiring hospitalization.
Severity 2	Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life-threatening status.
Severity 3	Injuries which pose an immediate life-threatening condition if not treated adequately and expeditiously. The majority of these injuries are the result of structural collapse and subsequent entrapment or impairment of the occupants.
Severity 4	Instantaneously killed or mortally injured.

Table 1-8 provides a summary of the casualties estimated for the earthquake scenarios considered.

Table 1-8: Estimated Casualties*

Type and Time of Scenario			Level 1: Medical treatment without hospitalization	Level 2: Hospitalization but not life threatening	Level 3: Hospitalization and life threatening	Level 4: Fatalities due to scenario event
San Andreas Fault	2A.M. (max. residential occupancy)	Commercial	3	1	0	0
		Commuting	0	0	0	0
		Educational	0	0	0	0
		Hotels	1	0	0	0
		Industrial	2	1	0	0
		Other Residential	78	22	3	5
		Single-Family	19	2	0	1
		Total	**104**	**26**	**3**	**6**
	2 P.M. (max educational, industrial, and commercial)	Commercial	201	64	11	21
		Commuting	0	1	1	0
		Educational	97	32	6	11
		Hotels	0	0	0	0
		Industrial	16	5	1	2
		Other Residential	18	5	1	1
		Single-Family	4	0	0	0
		Total	**336**	**107**	**19**	**35**
	5 P.M. (peak commute time)	Commercial	161	50	9	16
		Commuting	8	10	18	3
		Educational	10	3	1	1
		Hotels	0	0	0	0
		Industrial	10	3	0	1
		Other Residential	29	8	1	2
		Single-Family	7	1	0	0
		Total	**226**	**76**	**28**	**23**
San Jacinto Fault	2A.M. (max. residential occupancy)	Commercial	0	0	0	0
		Commuting	0	0	0	0
		Educational	0	0	0	0
		Hotels	0	0	0	0
		Industrial	0	0	0	0
		Other Residential	3	0	0	0
		Single-Family	7	1	0	0
		Total	**10**	**1**	**0**	**0**
	2 P.M. (max educational, industrial, and commercial)	Commercial	7	1	0	0
		Commuting	0	0	0	0
		Educational	2	0	0	0
		Hotels	0	0	0	0
		Industrial	1	0	0	0
		Other Residential	1	0	0	0
		Single-Family	1	0	0	0
		Total	**12**	**2**	**0**	**0**
	5 P.M. (peak commute) time)	Commercial	6	1	0	0
		Commuting	0	0	0	0
		Educational	0	0	0	0
		Hotels	0	0	0	0
		Industrial	0	0	0	0
		Other Residential	1	0	0	0
		Single-Family	3	0	0	0
		Total	**11**	**2**	**0**	**0**

*Based on a population base of 64,324.

The analysis indicates that the worst time for a San Andreas fault earthquake to occur in La Quinta is during maximum educational, industrial and commercial occupancy loads, such as at 2 o'clock in the afternoon. An earthquake on the San Andreas fault sometime during the day is anticipated to cause hundreds of Level 1 and Level 2 casualties, most likely related to people trying to run outside and in the process bumping into overturned furniture, being hit by flying objects falling off shelves in stores and offices, and by falling debris resulting from the structural damage to primarily commercial and educational buildings. Dozens of Level 3 and Level 4 casualties are anticipated as a result of damage to primarily commercial structures, followed by educational structures. Significant damage to steel, concrete, and reinforced masonry structures, construction types typically used in non-residential applications, appears to control the anticipated injury severity levels and counts, as extensive damage to these types of buildings generates heavy debris that can result in significant numbers of trauma cases. Damage to residential structures, typically of wood-frame construction, result in mostly Level 1 and Level 2 injuries. For these same reasons, an earthquake occurring during maximum residential occupancy loads, such as at 2 o'clock in the morning, results in the least number of casualties, with most injuries classified as Level 1 and Level 2.

Many injuries are anticipated to occur if the San Andreas fault earthquake occurs during maximum commuting hours, such as at 5 o'clock in the evening, although similar numbers would be expected if the earthquake occurs between about 7 and 9 o'clock in the morning, or between 4 and 6 o'clock in the evening. These casualties are the result of increased traffic accidents due to drivers losing control of their vehicles, vehicle crashes due to stoplights being out, and the collapse of bridges and broken roadways (Shoaf, 2008).

An earthquake on the San Jacinto fault is anticipated to cause essentially the same number of casualties in the La Quinta area regardless of the time of day when the earthquake occurs. Most injuries will be classified as Level 1, with damage to commercial structures controlling the number of casualties anticipated if the earthquake occurs during the day, and damage to residential structures controlling the number and type of injuries that are expected if the earthquake occurs at night. An earthquake on the San Jacinto fault is not expected to result in any injuries to commuters.

1.9.3 Damage to Critical and Essential Facilities

HazUS breaks critical facilities into two groups: (1) essential facilities, and (2) high potential loss (HPL) facilities. Essential facilities are those parts of a community's infrastructure that must remain operational after an earthquake. Buildings that house essential services include hospitals, emergency operation centers, fire and police stations, schools, and communication centers. HPL or high-risk facilities are those that if severely damaged, may result in a disaster far beyond the facilities themselves. Examples include power plants, dams and flood control structures, and industrial plants that use or store explosives, extremely hazardous materials or petroleum products in large quantities.

Other critical facilities not considered in the HazUS analysis but that should be considered in both emergency preparedness and emergency response operations given their potential impact on the community include: (1) High-occupancy facilities, such as large assembly facilities, and large multi-family residential complexes because of the potential for a large number of casualties or crowd-control problems; (2) dependent care facilities, such as preschools, schools, rehabilitation centers, prisons, group care homes, nursing homes, and other facilities that house populations with special evacuation considerations; and (3) economic facilities, such as banks, archiving and vital, record-keeping facilities, and large industrial or commercial centers, that should remain operational to avoid severe economic impacts.

There are no hospitals in La Quinta. The three closest hospitals to the study area include: 1) JFK Memorial Hospital in Indio, 2) Eisenhower Medical Center in Rancho Mirage, and 3) Desert Regional Medical Center in Palm Springs. The following table summarizes information about these hospitals, including their expected functionality immediately following the two earthquake scenarios considered for this study.

Table 1-9: Hospitals Near the La Quinta General Plan Area

Hospital Name	Address, Distance from La Quinta	Bed Capacity	Expected Functionality after Earthquakes
JFK Memorial Hospital	47111 Monroe Street, Indio, CA 92201; approximately 2 miles east of La Quinta, 7 miles from downtown La Quinta	158 beds	Expected to be non-functional immediately after a M7.8 earthquake on the San Andreas fault; nearly 70% functional immediately after a M7.2 earthquake on the San Jacinto fault.
Eisenhower Medical Center	39000 Bob Hope Drive, Rancho Mirage, CA 92270; approximately 8 miles from northern La Quinta	313 beds	Expected to be almost non-functional immediately after a M7.8 earthquake on the San Andreas fault; approximately 56% functional immediately after a M6.8 earthquake on the San Jacinto fault.
Desert Regional Medical Center	1150 N. Indian Canyon Road, Palm Springs, CA 92262 approximately 20 miles from northern La Quinta, 24 miles from downtown La Quinta	367 beds	Expected to be non-functional immediately after a M7.8 earthquake on the San Andreas fault; approximately 60% functional immediately after a M6.8 earthquake on the San Jacinto fault.

Hospitals lose functionality as a result of both structural and non-structural damage. Even if the hospital buildings perform well, equipment failures can result in a lack of primary and/or secondary emergency power. Rupture of water lines, and shearing of fire sprinkler heads can result in significant water damage. This is what happened at the Olive View Medical Center in Sylmar as a result of the 1994 Northridge earthquake, requiring the evacuation of 300 patients, and the performance of health care functions in the parking lot for about 30 hours (Pickett, 2008). The M7.8 ShakeOut scenario is expected to cause an immediate interruption of commercial electrical power (Pickett, 2008). As a result, all hospitals in the region should have emergency generators that would kick in automatically upon loss of commercial power, with automatic transfer switches that make the transition from the commercial power to the emergency power sources. All three hospitals near La Quinta are expected to be impacted by the extensive damage to the external supply of potable water, which in this region could take weeks to months to be repaired. The external waste water system is also expected to be damaged extensively. The ShakeOut scenario is also expected to result in an immediate interruption of commercial telecommunication systems, which would impact the hospitals directly. Internal communications within the hospitals may also be impaired as a result of structural damage, power losses, and water damage that would cause the circuit breakers to be tripped open.

Given that all three hospitals in the region are anticipated to be non-functional immediately following a M7.8 earthquake on the San Andreas fault, and that hundreds of people in the region are expected to require medical attention, alternate medical providers both within and outside the community should be identified. Possible sources of care for Level 1 and 2 casualties include urgent care and out-patient medical facilities, and private doctors' offices. Severely hurt patients may have to be airlifted to other hospitals in southern California or Arizona. It is also important to mention that access to hospitals in communities on the east side of the San Andreas fault could be difficult if the fault rupture damages the access roads. The data indicate that most injuries resulting from an earthquake on the San Jacinto fault will not require hospitalization, and since the regional hospitals are all expected to be relatively functional following that earthquake, the San Jacinto earthquake scenario is not expected to place significant additional demands on the local hospitals.

Other critical facilities in the HazUS database for La Quinta include 322 school buildings, three fire stations, one police station, and one emergency operations center. The expected damage to these essential facilities is summarized in Table 1-10, below. High potential loss facilities in the area include four dams (the East Side Detention Dike No. 1, and West Side Detention Dikes Nos. 2, 3 and 4), zero hazardous materials site, zero military installations, and zero nuclear power plants. None of the dams are considered "high hazard."

Table 1-10: Expected Damage to Essential Facilities

Scenario	Classification	Total #	# Facilities		
			At Least Moderate Damage >50%	Complete Damage >50%	With Functionality >50% on Day 1
San Andreas Fault	Hospitals	3	3	1	0
	Schools	322	103	22	39
	EOCs	1	0	0	1
	Fire Stations	3	0	0	2
	Police Stations	1	0	0	0
San Jacinto Fault	Hospitals	3	0	0	3
	Schools	322	0	0	315
	EOCs	1	0	0	1
	Fire Stations	3	0	0	3
	Police Stations	1	0	0	1

According to the earthquake scenario results, the San Andreas fault will cause at least moderate damage to 103 school buildings, with 22 school buildings displaying complete damage to more than 50% of their structure. Thirty-nine school buildings are not expected to be more than 50% functional on the day after the earthquake. By comparison, the San Jacinto earthquake scenario is not expected to cause significant damage to any of the school buildings in the HazUS area. Furthermore, only seven school buildings are not expected to be more than 50% functional the day after the earthquake. This lack of functionality is most likely the result of non-structural failures, such as toppled unanchored bookshelves, or overturned computer equipment.

Two of the three fire stations, the one police station and the City's EOC are expected to be more than 50% functional on the day after the San Andreas earthquake. All essential facilities, with the exception of the school buildings discussed above are expected to be more than 50% functional on the day after a San Jacinto fault earthquake.

1.9.4 Economic Losses

HazUS estimates structural and non-structural repair costs caused by building damage and the associated loss of building contents and business inventory. Building damage can cause additional losses by restricting the building's ability to function properly. Thus, business interruption and rental income losses are estimated. HazUS divides building losses into two categories: (1) direct building losses and (2) business interruption losses. Direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. Business interruption losses are associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake.

Earthquakes may produce indirect economic losses in sectors that do not sustain direct damage. All businesses are forward-linked (if they rely on regional customers to purchase their output) or backward-linked (if they rely on regional suppliers to provide their inputs) and are thus potentially vulnerable to interruptions in their operation. Note that indirect losses are not confined to immediate customers or suppliers of damaged enterprises. All of the successive rounds of customers of customers, and suppliers of suppliers are affected. In this way, even limited physical earthquake damage causes a chain reaction, or ripple effect, that is transmitted throughout the regional economy.

The model estimates that total economic losses in the La Quinta area will range from nearly $178 million for an earthquake on the San Jacinto fault to about $911 million for an earthquake on the San Andreas fault. These figures include building-, transportation-, and lifeline-related losses based on the region's available inventory. Business-related losses include direct building losses (capital stock losses such as structural and non-structural damage, and damage to contents and inventory), and business interruption losses (loss of income from wages, rental properties, relocation expenses, and capital related). Building-related losses estimated for the two earthquake scenarios are summarized in Table 1-11 below. Transportation and utility lifeline losses are summarized in the following sections.

Direct building losses, excluding damage to contents and inventory, are estimated to account for 65 and 68 percent of the building-related economic losses in the La Quinta region as a result of an earthquake on the San Andreas and San Jacinto faults, respectively. The loss analysis shows that residential occupancies would suffer the most, with a substantial amount of the property damage due to non-structural losses; that is, cosmetic damage to a structure that does not result in the collapse of the structure, and is repairable. This is essentially what building codes are designed to do. Business interruption losses account for about 15 to 16 percent of the losses in the region.

Table 1-11: Building-Related Economic Losses (in millions of $)
Estimated as a Result of Two Earthquake Scenarios

Scenario	Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
San Andreas	Income Losses	Wage	0.00	4.34	27.78	0.36	1.98	34.47
		Capital-Related	0.00	1.89	32.61	0.21	1.35	36.06
		Rental	3.81	14.32	9.06	0.07	0.53	27.80
		Relocation	13.72	13.42	12.12	0.45	9.29	48.99
		SubTotal	17.53	33.97	81.57	1.09	13.15	147.31
	Capital Stock Losses	Structural	29.88	26.03	20.06	2.18	34.38	112.53
		Non-Structural	185.60	127.18	79.20	8.95	77.66	478.60
		Content	76.80	30.68	34.13	5.14	20.96	167.71
		Inventory	0.00	0.00	0.69	1.00	2.69	4.37
		SubTotal	292.28	183.89	134.09	17.28	135.68	763.22
	Total		**309.82**	**217.86**	**215.66**	**18.37**	**148.84**	**910.53**
San Jacinto	Income Losses	Wage	0.00	0.44	5.00	0.04	0.16	5.64
		Capital-Related	0.00	0.19	5.94	0.02	0.08	6.23
		Rental	1.47	1.85	1.53	0.01	0.05	4.91
		Relocation	5.11	1.97	1.91	0.09	0.88	9.96
		SubTotal	6.57	4.45	14.38	0.16	1.17	26.74
	Capital Stock Losses	Structural	12.34	2.95	2.20	0.24	2.42	20.15
		Non-Structural	66.77	17.57	9.70	0.85	5.57	100.47
		Content	20.27	4.10	4.36	0.49	1.51	30.74
		Inventory	0.00	0.00	0.07	0.10	0.18	0.35
		SubTotal	99.38	24.62	16.34	1.68	9.68	151.71
	Total		**105.95**	**29.07**	**30.73**	**1.85**	**10.85**	**178.45**

1.9.5 Transportation Damage

Lifelines are those services that are critical to the health, safety and functioning of the community. They are particularly essential for emergency response and recovery after an earthquake. Furthermore, certain critical facilities designed to remain functional during and immediately after an earthquake may be able to provide only limited services if the lifelines they depend on are disrupted. Lifeline systems include transportation and utilities. Transportation systems are discussed in more detail in the following paragraphs, whereas utility lifelines are discussed further in the next section.

HazUS divides the transportation system into seven components: highways, railways, light rail, bus, ferry, ports, and airports. Only highways, railways, and airports are relevant to the area covered in the analysis for La Quinta. The replacement value for the transportation system in the study area is estimated at nearly $771.3 million, with the highway segments ($677.90 million) and airport runways ($73.3 million) accounting for most of this value. The HazUS inventory for the study region includes over 201 kilometers (108.5 miles) of highways and 20 bridges.

Damage to the transportation system in La Quinta is based on a generalized inventory of the region, which includes areas outside of the city, since the transportation network extends beyond corporate boundaries. Table 1-12 provides damage and loss estimates for specific components of the transportation system. The results of this analysis suggest that the transportation system in La Quinta will be impacted by an earthquake on the San Andreas fault, with about half of the bridges in the highway system at least moderately damaged and less than 50% functional one week after the earthquake. The facilities at the Thermal Airport are also expected to be at least moderately damaged. Economic losses to the transportation system as a result of the ShakeOut scenario are estimated at about $11 million. A M7.2 earthquake on the San Jacinto fault is estimated to cause minor damages to the transportation in the La Quinta area, amounting to about $0.9 million.

The model assumes that roadway segments and railroad tracks are damaged by ground failure only, but past earthquakes have shown that ground shaking can cause deformation to the ground surface, with resultant damage to the roadways. Therefore, the economic loss estimates for the highway system presented above may be low. It is also important to remember that these same transportation systems may be significantly impacted in areas outside of La Quinta due to surface fault rupture, landsliding, liquefaction or other types of seismically induced ground deformation, which could directly and indirectly have an impact on La Quinta's residents (especially those that commute) and businesses that rely on products shipped on these transportation systems.

Table 1-12: Transportation System – Expected Damage and Economic Losses

Scenario	System	Component	Locations/ Segments	With at Least Moderate Damage	With Complete Damage	Functionality >50%		Economic Loss (Millions $)
						After Day 1	*After Day 7*	
San Andreas	Highway	Segments	6	0	0	6	6	0.00
		Bridges	20	12	8	9	10	7.78
	Railways	Segments	4	0	0	4	4	0.00
	Airport	Facilities	1	1	0	0	1	3.10
		Runways	2	0	0	2	2	0.00
San Jacinto	Highway	Segments	6	0	0	6	6	0.01
		Bridges	20	0	0	20	20	0.08
	Railways	Segments	4	0	0	4	4	0.00
	Airport	Facilities	1	0	0	1	1	0.81
		Runways	2	0	0	2	2	0.00

1.9.6 Utility Systems Damage

Utility lifelines include potable water, wastewater, natural gas, crude and refined oil, electric power, and communications. The improved performance of lifelines in the 1994 Northridge earthquake relative to the 1971 San Fernando earthquake, shows that the seismic codes that were upgraded and implemented after 1971 have been effective. Nevertheless, the impact of the Northridge earthquake on lifeline systems was widespread and illustrated the continued need to study earthquake impacts, upgrade substandard elements in the systems, provide redundancies, improve emergency response plans, and provide adequate planning, budgeting and financing for seismic safety. Water supply facilities, such as dams, reservoirs, pumping stations, water treatment plants, and distribution lines are especially critical after an earthquake, not only for drinking water, but to fight fires. Possible failure of dams and above-ground water storage tanks as a result of an earthquake is discussed further in Chapter 3.

If site-specific lifeline utility data are not provided for these analyses, HazUS performs a statistical calculation based on the population served to develop an estimate of the total length of pipelines that comprise the potable water, natural gas, wastewater and oil systems. From this inventory, the model then calculates the expected number of leaks and breaks in these systems. The replacement value for the utility lifeline system in the La Quinta study area is estimated at $109.9 million.

Table 1-13 summarizes the expected damage to the potable water, waste water, and natural gas systems in La Quinta as a result of the earthquake scenarios on the San Andreas and San Jacinto faults. The models suggest that the potable water, waste water and natural gas systems in La Quinta will experience extensive and minor damage as a result of an earthquake on the San Andreas and San Jacinto faults, respectively. The San Andreas earthquake scenario is expected to cause thousands of leaks and breaks in these systems. Where potable water lines extend across leach fields or occupy the same trench as sewer lines, breaks in these lines could result in contamination of the potable water supply. The potable water system in particular is estimated to be so extensively damaged that the community is anticipated to be without potable water for a minimum of three months (see Table 1-14). Given these results, La Quinta residents should be strongly encouraged to store at least a five-day supply of drinking water for the entire household (including pets), allowing families to be self-sufficient immediately following the earthquake, and giving the City and the Coachella Valley Water District some time to organize and develop alternate methods of water delivery to their residents and customers.

Table 1-13: Expected Utility System Pipeline Damage

Scenario	System	Total Pipelines Length (kms)	Number of Leaks	Number of Breaks	Economic Loss ($Millions)
San Andreas	Potable Water	781	17,311	4,328	77.90
	Waste Water	468	13,692	3,423	98.78
	Natural Gas	312	14,636	3,659	65.86
San Jacinto	Potable Water	781	105	26	0.47
	Waste Water	468	83	21	4.42
	Natural Gas	312	88	22	0.40

Table 1-14 shows the expected performance of the potable water, and electric power systems using empirical relationships based on the number of households served in the area. As briefly discussed above, and according to the models, an earthquake on the San Andreas fault is expected to have a significant negative impact on both the potable water and electric power services – essentially all households in the La Quinta study area are expected to have no potable water for at least 90 days (3 months) following the earthquake, and possibly even longer. The number of pipe breaks is expected to be such that the entire water system is going to have to be recreated. Given that the M7.8

ShakeOut scenario is going to impact a very large area, “there will not be enough pipe and connectors or trained manpower to repair all the breaks quickly. The worst hit areas may not have water in the taps for 6 months” (Jones and others, 2008).

Thousands of households are also expected to be without electric power following the earthquake, but repairs to this system are expected to occur more quickly. Thus, about 8,300 households are expected to be without power on the first day after the earthquake, but by day 7, only 2,200 households would still be without power.

Table 1-14: Expected Performance of Potable Water and Electric Power Services

Scenario	Utility	Number of Households without Service*				
		Day 1	Day 3	Day 7	Day 30	Day 90
San Andreas	Potable Water	20,789	20,789	20,789	20,789	20,786
	Electric Power	8,331	5,284	2,237	439	11
San Jacinto	Potable Water	0	0	0	0	0
	Electric Power	0	0	0	0	0

*Based on Total Number of Households = 20,789

The San Jacinto fault scenario, on the other hand, is not expected to cause any loss of the potable water and electric power systems in the La Quinta area.

1.9.7 Shelter Needs

Earthquakes can cause loss of function or habitability of buildings that contain housing. Displaced households may need alternative short-term shelter, provided by family, friends, temporary rentals, or public shelters established by the City, County or by relief organizations such as the Red Cross. Long-term alternative housing may require import of mobile homes, occupancy of vacant units, net emigration from the impacted area, or, eventually, the repair or reconstruction of new public and private housing. The number of people seeking short-term public shelter is of most concern to emergency response organizations. The longer-term impacts on the housing stock are of great concern to local governments, such as cities and counties.

HazUS estimates that about 175 households in La Quinta will be displaced due to the San Andreas fault earthquake modeled for this study, and that about 141 people will seek temporary shelter in public shelters (see Table 1-15 below). Considering that the region is anticipated to be without potable water for at least a month, if not longer, the displaced households number for the ShakeOut scenario given below may be significantly underestimated. An earthquake on the San Jacinto fault is anticipated to displace about 14 households, with approximately 10 people seeking temporary shelter in public shelters. In both scenarios, those people displaced that do not seek short-term shelter in public facilities are expected to find alternate temporary housing with family or friends.

The actual number of people seeking shelter may also be larger than the estimates given because of the fairly large percentage of Hispanics in the General Plan area. Past history has shown that Hispanics, especially those of Mexican and Central American ancestry, generally prefer to camp out in parks and other open spaces rather than return to their house soon after an earthquake, even if their house appears to be undamaged. This was observed in the greater Los Angeles area following the 1994 Northridge earthquake, as well as other previous earthquakes in California, such as the 1987 Whittier Narrows and 1989 Loma Prieta earthquakes (Tierney, 1994; Tierney, 1995; Andrews, 1995).

Table 1-15: Estimated Shelter Requirements

Scenario	Displaced Households	People Needing Short-Term Shelter
San Andreas fault	175	141
San Jacinto fault	14	10

1.10 Summary and Recommendations

Since it is not possible to prevent an earthquake from occurring, local governments, emergency relief organizations, and residents are advised to take action and develop and implement policies and programs aimed at reducing the effects of earthquakes. Individuals should also exercise prudent planning to provide for themselves and their families in the aftermath of an earthquake. This is particularly important in the Coachella Valley area, and other areas immediately adjacent to or bisected by the southern San Andreas fault.

Earthquake Sources:

- There are no known earthquake sources within the La Quinta General Plan area. However, the city is within 4 miles of the San Andreas fault, and about 16 miles from the San Jacinto fault. Both of these faults could generate an earthquake in the next 30 years, with the San Andreas fault having a 59% probability of causing an earthquake of at least magnitude 6.7 in the next 30 years. Therefore, all proposed new developments in La Quinta should incorporate near-source factors in the design of the structures.

- A number of historic earthquakes have caused moderate ground shaking in La Quinta. Strong ground shaking due to future earthquakes on nearby regional sources should be expected and designed for.

Design Earthquake Scenarios:

- Geologists, seismologists, engineers and urban planners typically use maximum magnitude and maximum probable earthquakes to evaluate the seismic hazard of a region, the assumption being that if we plan for the worst-case scenario, smaller earthquakes that are more likely to occur can be dealt with more effectively.

- The San Andreas and San Jacinto faults have the potential to generate earthquakes that would be felt strongly in the La Quinta region. Unfortunately, we cannot predict when a fault will break causing an earthquake, but we can anticipate the size of the resulting earthquake and estimate the level of damage that the earthquake would generate in the region. The southern section of the San Andreas fault closest to La Quinta is thought capable of generating a M7.8 to 8.0 earthquake. Individual segments of this section of the fault could generate M7.2 to M7.5 earthquakes. Similarly, the sections of the San Jacinto fault closest to La Quinta are thought capable of generating earthquakes of M6.6 to M7.2. Most other faults within 100 km (62 miles) of the city can generate earthquakes as large or larger than the M_w 6.7 Northridge earthquake, the single most-expensive earthquake yet to impact the United States.

- The loss estimation analyses conducted for this study indicate that the San Andreas fault would be the worst-case scenario for La Quinta, causing significant damage in the city, with economic losses estimated at more than $900 million. The San Jacinto fault is not expected to cause as much damage in the General Plan area because the maximum magnitude earthquake that it is capable of generating is significantly smaller, and it is also farther away.

<u>Fault Rupture and Secondary Earthquake Effects:</u>

- No active faults have been mapped within the La Quinta General Plan area.

- The California Geological Survey (CGS) has not conducted mapping in the La Quinta area under the Seismic Hazards Mapping Act. This report presents a liquefaction susceptibility map that was prepared using a similar but simpler form of the method used by the California Geological Survey (geotechnical data providing density of the near-surface sediments were not reviewed). Shallow ground water levels (less than 30 feet from the ground surface) have been reported historically in the eastern part of the General Plan area. Although the groundwater levels have dropped recently as a result of increased pumping of the underlying aquifers, increased recharge of the basin could result in a rise in the water levels to past historical highs. Studies in accordance with the guidelines prepared by the CGS should be conducted in those areas identified as susceptible to liquefaction, at least until sufficient studies have conclusively shown whether or not the sediments are indeed susceptible to liquefaction.

- Precariously perched rocks are common on the mountains within and to the south-southwest of the La Quinta General Plan area. Earthquake-induced ground shaking could dislodge some of the rocks, posing a rockfall hazard to areas adjacent to and below these slopes.

- Those areas of La Quinta underlain by youthful unconsolidated alluvial sediments may be susceptible to seismically induced settlement. Geotechnical studies to evaluate this potential hazard should be conducted in areas underlain by Holocene sediments where developments are proposed. If the sediments are found to be susceptible to this hazard, mitigation measures designed to reduce settlement should be incorporated into the design.

<u>Earthquake Hazard Reduction</u>:

- Most of the loss of life and injuries that occur during an earthquake are related to the collapse of hazardous buildings and structures, or from non-structural components, including contents, in those buildings. The HazUS analyses conducted for this study indicate that more than 74% of the residential structures other than single-family homes (that is, multi-family residential buildings, including duplexes, condominiums and apartments) will suffer at least moderate damage as a result of an earthquake on the San

Andreas fault. Nearly 59% of the industrial structures, 58% of the agricultural, and 54% of commercial structures are also expected to be at least moderately damaged by a San Andreas fault earthquake. Similarly, about 50% of the education, government and religion buildings in the study area will suffer at least moderate damage. Nearly 95% of the manufactured homes in the area will be damaged.

- The HazUS results indicate that the worst time for an earthquake to occur on the San Andreas fault is during the day, during maximum education, commercial and industrial laods. Because many of the buildings damaged generate heavy debris, an earthquake during the day is anticipated to generate dozens of Level 3 and 4 injuries, in addition to hundreds of Level 1 and 2 injuries.

- The regional hospitals are not expected to be able to meet the demand for medical care in the aftermath of a San Andreas earthquake in the area. Emergency management personnel and planners need to develop a contingency plan that provides for medical care at facilities other than the local hospitals, in addition to agreements with hospitals outside of the region that can provide assistance with Level 3 and 4 casualties. Given the extensive damage anticipated to the transportation system, most victims that need to be transported elsewhere for treatment will have to be airlifted out of the area.

- The inventory and retrofit of potentially hazardous structures, such as pre-1952 wood-frame buildings, concrete tilt-ups, pre 1971- reinforced masonry, soft-story buildings and especially mobile homes, are recommended.

- The best mitigation technique in earthquake hazard reduction is the constant improvement of building codes with the incorporation of the lessons learned from past earthquakes. This is especially true in areas not yet completely developed. In addition, current building codes should be adopted for re-development projects that involve more than 50% of the original cost of the structure. Current building codes incorporate two significant changes that impact the city of La Quinta. First, there is recognition that soil types can have a significant impact on the amplification of seismic waves, and second, the proximity of earthquake sources will result in high ground motions and directivity effects. However, for those areas of La Quinta already developed, and given that building codes are generally not retroactive, the adoption of the most recent building code is not going to improve the existing building stock, unless actions are taken to retrofit the existing structures. Retrofitting existing structures to the most current building code is in most cases cost-prohibitive and not practicable. However, specific retrofitting actions, even if not to the latest code, that are known to improve the seismic performance of structures should be attempted.

- While the earthquake hazard mitigation improvements associated with the latest building code address new construction, the retrofit and strengthening of existing structures requires the adoption of ordinances. The City of La Quinta should consider the implementation of a mandatory ordinance aimed at retrofitting older wood-frame residential buildings that are not tied-down to their foundations, pre-cast concrete buildings, steel-frame buildings, soft-story structures, and manufactured housing. Although retrofitted buildings may still incur severe damage during an earthquake, their mitigation results in a substantial reduction of casualties by preventing collapse.

- Adoption of new building codes does not mitigate local secondary earthquake hazards such as liquefaction and ground failure. Therefore, these issues are best mitigated at the local level. Avoiding areas susceptible to earthquake-induced liquefaction or settlement is generally not feasible. The best alternative for the City is to require "special studies" within these zones for new construction, as well as for significant redevelopment, and require implementation of the engineering recommendations for mitigation.

- Effective management of seismic hazards in La Quinta includes technical review of consulting reports submitted to the City. For projects in areas susceptible to liquefaction, the City should consider following the State law that requires that the reviewer be a licensed engineering geologist and/or civil engineer having competence in the evaluation and mitigation of seismic hazards (CCR Title 14, Section 3724). Because of the interrelated nature of geology, seismology, and engineering, most projects will benefit from review by both the geologist and civil engineer. The California Geological Survey has published guidelines to assist reviewers in evaluating site-investigation reports (CDMG, 1997; CGS, 2008).

- The HazUS analyses suggest that the potable water, wastewater and electric systems in La Quinta will be extensively damaged by an earthquake on the San Andreas fault, with thousands of leaks and breaks anticipated in the potable water system. Hardest hit areas may be without water at the tap for up to six months. The City and its lifeline service providers should consider retrofitting the older pipelines in these systems, to reduce the number of potential breaks as a result of corrosion and age, in addition to developing plans to truck in water that is delivered directly to the City residents. Residents of the La Quinta area should be encouraged to store at least a 5-day supply of water for all family members, including pets, so that they can be self-sufficient immediately following the earthquake.

CHAPTER 2: GEOLOGIC HAZARDS

Geologic hazards are generally defined as surficial earth processes that have the potential to cause loss or harm to the community or the environment. The basic elements involved in the assessment of geologic hazards are: 1) underlying geology (including soil types, rock types, groundwater, and zones of weakness like faults, fractures, and bedding); 2) topography; 3) climate; and 4) land use. The geology and types of geologic hazards affecting the La Quinta General Plan area are discussed in the following sections.

2.1 Physiographic and Geologic Setting

The La Quinta General Plan area is located across the boundary of two very distinct physiographic provinces, each having a unique landscape formed by geologic and climatic processes. The valley portion of La Quinta is part of the Colorado Desert Province, a low-lying basin that stretches from the Banning Pass to the Mexican border. The southwestern portion of La Quinta reaches into the Santa Rosa Mountains, which are part of the Peninsular Ranges Province, a region characterized by a series of northwest-trending valleys and mountain ranges.

Elevations across the valley floor, within the General Plan area, range between approximately 140 feet above sea level at the northern end, to about 120 feet below sea level at the southeastern corner. The highest point within the General Plan mountain area is at an elevation of about 1,600 feet above sea level; this elevation is about 4,800 feet lower than Martinez Mountain, the highest peak within the ridge forming the immediate backdrop to La Quinta.

The largest drainage in the region, the Whitewater River, crosses the northern part of the city. The river intermittently drains the surrounding highlands, as well as the northern part of the Coachella Valley. Streambeds in the Santa Rosa Mountains are dry most of the year, and have significant flow only during and immediately after storms, when they carry large amounts of runoff for short periods of time. Several canals and aqueducts cross the General Plan area, leading to the modern Lake Cahuilla, a man-made storage reservoir.

Geologically speaking, the valley portion of La Quinta is situated at the edge of a broad structural depression known as the Salton Trough. Over the last million years or so, the tectonically subsiding trough has filled with a thick sequence of sediments that now forms the nearly flat valley floor. Although the trough is physically continuous from the San Gorgonio Pass to the Gulf of California, early settlers in the area gave different names to the northern and southern portions: The portion north of the Salton Sea is known as the Coachella Valley or Indio region, and the portion south of the Salton Sea is known as the Imperial Valley. La Quinta is in the southern part of the Coachella Valley.

The sedimentary sequence infilling the trough records the recent geologic history of the area. For instance, the Imperial Formation, a geologic unit exposed in Garnet Hill to the north, but occurring predominantly at depth, is of marine origin, indicating the trough was inundated by the sea in latest Miocene to late Pliocene time (about 6 to 2 million years ago). In the last about two million years, these marine sediments were in turn overlain by a thick sequence of terrestrial sediments shed from the adjacent highlands. At about the same time, the Colorado River worked to build its delta at the Gulf of California, effectively forming a dam by accumulating sediment at the mouth of the river and turning the trough into a closed basin. The presence of interlayered lakebed sediments in the stratigraphic sequence indicates the basin was periodically inundated with fresh water derived from the Colorado River as it migrated back and forth across its delta. Ancient Lake Cahuilla, the last, and possibly one of the largest of the ancient lakes to occupy the basin, completely evaporated about 400 years ago when the Colorado River again changed course and flowed directly into the Gulf of California. The size of ancient Lake Cahuilla is estimated at over 2,000 square miles, covering most of the basin, including the valley portion of La Quinta's General Plan area. In fact, the lake's paleo-shoreline transects the city of La Quinta, near the base of the mountains (see Plate 2-1). The Salton Sea, which originally formed as water from the Colorado River was unintentionally diverted to the basin by man, is considerably smaller by comparison.

The physical features described above reflect geologic and climatic processes that have affected this region in the last few million years. The physiographic and geologic histories of the La Quinta area are important in that they control to a great extent the geologic hazards, as well as the natural resources, within the city. For example, wind-blown sand erosion poses a significant hazard in the Coachella Valley due to funneling of fierce winds through the steep mountain passes, although locations at the base of the mountains are somewhat sheltered from this hazard. Alternatively, areas in and adjacent to the mountains are more likely to be impacted by rock falls and unstable slopes. Regional tectonic subsidence along the valley floor, concurrent with uplift of the adjacent mountains, is responsible to a great extent for the rapid deposition of poorly consolidated alluvium that is susceptible to consolidation and/or collapse. On the other hand, the deep alluvium-filled basin, which is bounded by relatively impermeable rock and faults, provides a natural underground reservoir (aquifer) for groundwater, one of the area's primary sources of domestic water.

The La Quinta General Plan area is located within a region that is changing rapidly. In fact, this area, which includes San Bernardino and Riverside counties, has the fastest-growing population in all of California. The central to northern sections of the city, on the valley floor proper, are currently the most heavily populated. Development is expanding however, and will eventually fill in the remainder of the valley areas, spreading out eastward toward the boundary with the city of Coachella, and southward, to the base of the mountains. The mountainous areas in the western and southwestern parts of the city are included in the Santa Rosa and San Jacinto Mountains National Monument and will remain as open space.

2.2 Earth Units and Their Engineering Properties

The general distribution of geologic units that are exposed at the surface is shown on the Geologic Map (Plate 2-1). This map is a slightly modified version of that published by Dibblee (2008). The general physical and engineering characteristics of each unit are summarized in the following sections.

2.2.1 Alluvial Sand and Gravel (map symbol: Qg)

This unit includes very young, unconsolidated alluvium deposited by the Whitewater River. Consisting of crudely bedded sand, silt, gravel, boulders, and debris deposited by floodwaters, these sediments are highly susceptible to erosion, reworking, and burial by future flooding. Although construction is generally not allowed in these floodways, roadways or pipelines may need to cross these areas out of necessity. River sediments are highly compressible, so bridge supports need to extend through the unconsolidated

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

Fault lines on the map are used solely to approximate the fault location. The width and location of the faults should not be used in lieu of site-specific investigations, evaluation, and design.

Detailed geologic investigations, including trenching studies, may make it possible to refine the location and activity status of a fault. All faults may not be shown. This map should be amended as new data become available and are validated.

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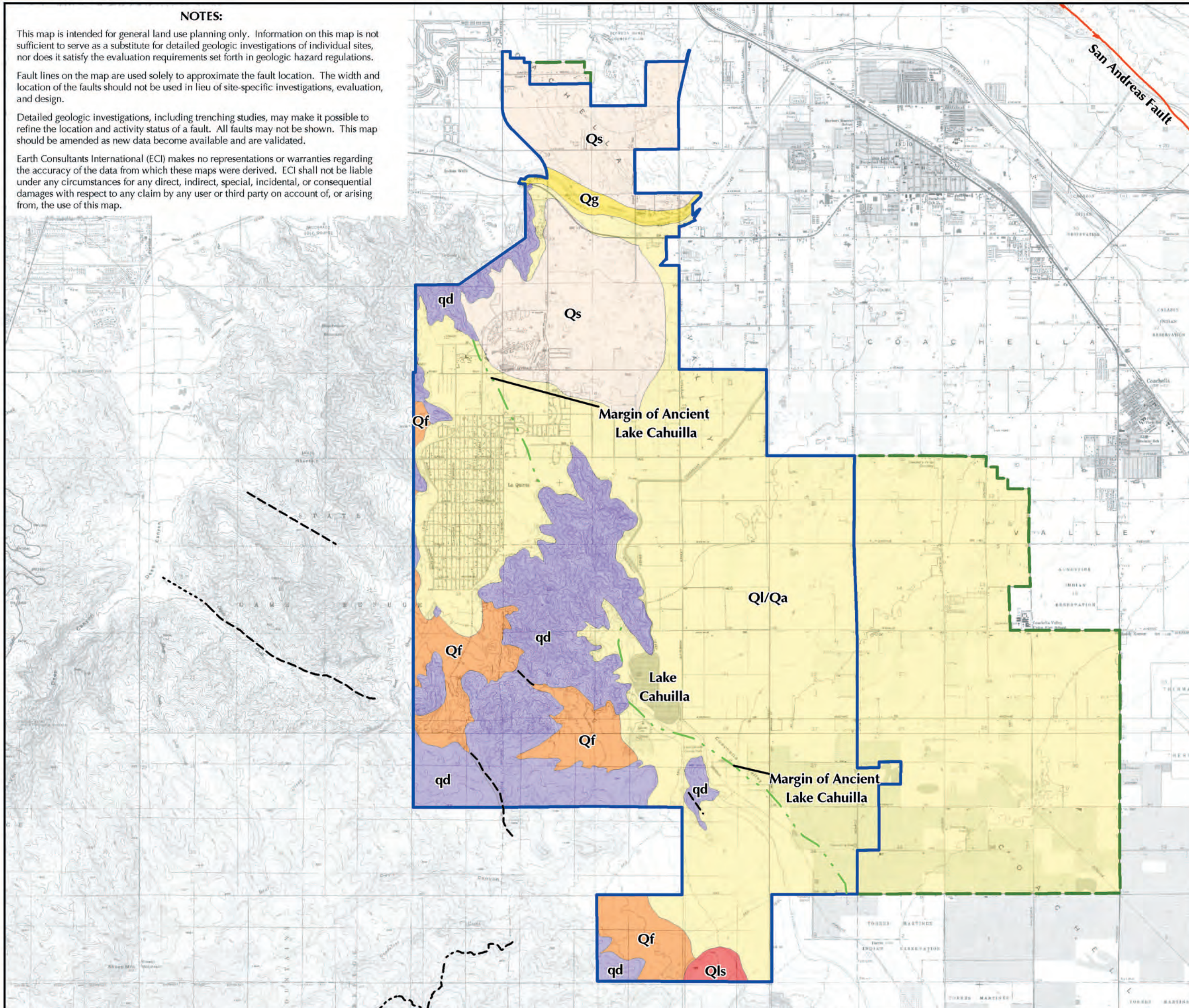

Geologic Map

La Quinta, California

Geologic Unit Descriptions

Qg	Alluvial sand and gravel of Whitewater River
Ql/Qa	Alluvial sand and clay of valley areas
Qf	Alluvial fan sand and gravel
Qs	Wind-laid dune sand
Qls	Landslide
Qd	Quartz diorite

Symbols

- Active Fault; solid where well located, dashed where approximately located, dotted where concealed or inferred.
- Bedrock (not active) Fault; dashed where approximately located, dotted where concealed or inferred. (See Plate 1-1 for additional information).
- Geologic Contact
- La Quinta City Boundary
- La Quinta Sphere of Influence

N S W E

6000 0 6000

Feet

2000 0 2000

Meters

Scale: 1:72,000

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997.
Sources: Modified from Dibblee (2008); Rogers (1965), and Matti and others (1983).

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Plate 2-1

sediments and anchored onto firm ground. Foundation elements placed in the river will be susceptible to scour from floodwaters or to damage from boulders carried by fast-moving waters.

2.2.2 Windblown Sand (map symbol: Qs)

Wind-blown sand is very common in the area, and mapped as a deposit throughout the northern portion of the city. The windblown (also called eolian) deposits typically consist of reworked alluvium. The strong winds in the area pick up and redistribute the silty sand and fine- to medium-grained sand fractions, forming shifting sand dunes (Qs).

Engineering issues in areas mapped as Qs include high susceptibility to erosion, settlement, and collapse.

2.2.3 Alluvial Deposits (map symbol: Qa)

The alluvium is primarily distributed along the base the Santa Rosa Mountains to the west. The older developed area of the city constructed in the lee of Eisenhower Mountain is built entirely on alluvium. Towards the valley these deposits are interbedded with fine-grained sediments deposited in the prehistoric lakes.

How and where these deposits were laid down have a significant bearing on the properties of these materials. Young near-surface alluvium often has organic debris, and is typically deposited rapidly by flash floods. As a result, the engineering issues affecting these geologically young deposits are: 1) compressibility, which occurs when additional loads are applied, and 2) collapse (hydroconsolidation) upon introduction of irrigation water if the deposit is dry. Being unconsolidated, the young alluvium is also highly susceptible to erosion. Alluvial deposits also have moderate to high permeability. Alluvial sediments are suitable for use as fill once the organic materials and oversized rocks are removed; however, they typically require the addition of water to achieve compaction.

2.2.4 Interbedded Lacustrine and Alluvial Deposits (map symbol: Ql/Qa)

Lacustrine (lake) sediments were deposited in ancient Lake Cahuilla and other large lakes that once inundated the Salton Trough as recently as 400 years ago. The lacustrine deposits are up to 300 feet thick and are interbedded with alluvial fan and colluvial sediments shed from the adjacent mountains.

Due to the saturation of deeper sediments by the ancient lakes, the collapse potential of those sediments below the youngest alluvium is believed to be low. Permeability is good (high) except where interbedded silt or clay layers retard the downward percolation of water. The potential for expansive soils is generally low, except where lake deposits of silt and clay are within or just below the depth of the elements of a structural foundation. Clay materials should not be placed in foundation areas if possible.

2.2.5 Alluvial Fan Deposits (map symbol: Qf)

Alluvial fan deposits are present on active fans emanating from the canyons that drain the local mountains. These sediments generally consist of poorly bedded silt, sand, and gravel. Boulders may be present in the upper part of the fans. The surfaces of the younger fans are relatively smooth and support a network of braided ephemeral streams. Older fan surfaces may be slightly elevated and dissected by entrenched stream channels. Fan deposits gradually transition into the finer-grained alluvial and lacustrine deposits in the lower valley areas.

Younger fan sediments are generally unconsolidated and subject to settlement or collapse. They are also susceptible to erosion by water or wind. Oversize rocks (those generally larger than about 12 inches) may hinder construction. Older fan deposits are generally more consolidated, but as a result of pedogenic soil development, they may have a higher percentage of clay at and near the surface, and the clayey section may be potentially expansive.

2.2.6 Landslide Deposits (map symbol: Qls)

Several large landslides have been mapped in the Santa Rosa Mountains above La Quinta (Dibblee, 2008). One of the largest and most spectacular is the Martinez Mountain Landslide, the bulk of which is located south of La Quinta (the toe of the slide encroaches onto the southern edge of the city). This landslide, which occurred in prehistoric times, is a rock avalanche consisting of coarse rubble. The debris was transported nearly six miles, dropping more than a mile in elevation, at velocities estimated to have exceeded 75 miles per hour (Baldwin, 1987). It is unknown what triggered the landslide, although seismic shaking has been suggested (Morton and Sadler, 1989).

From an engineering perspective landslides are generally considered unstable. Some slides may be compressible, especially around the margins, if subject to additional loads (such as deep fill embankments), or in some cases they may become reactivated during strong seismic shaking or by continued undercutting by streams at the toe.

2.2.7 Quartz Diorite (map symbol: qd)

The oldest geologic unit in the La Quinta area consists of very hard, crystalline rock that forms the mountains and is buried beneath the alluvium. Rock classifications are based primarily on genesis, texture, and mineral composition. Because crystalline rocks are usually highly variable in texture and mineralogy, often grading from one type to another, the units are typically named by the dominant rock type. Based on genesis alone, rocks underlying La Quinta are plutonic, meaning that the rocks crystallized from the molten state deep within the Earth's crust. Plutonic rocks generally have large grains that can easily be seen without magnification, and often have a spotted appearance. The rock forming La Quinta's mountains is light-colored and has a mineral assemblage that most closely aligns with quartz diorite (Dibblee, 2008). Most of this rock crystallized from a magma that was emplaced over 65 million years ago.

The durability of this unit results in the formation of the steep slopes and deep canyons within and above the city. The rock is very hard where not highly weathered, and cannot be excavated easily. It is typically non-water bearing and has low to moderately low permeability, except where joints and fractures provide avenues for water to move in and around the rock mass. Crystalline rocks provide strong foundation support and are generally non-expansive. Slope stability is generally good, however these rocks contain fractures and cooling joints that may locally serve as planes of weakness along which slope instability can occur. Very steep roadcuts are most vulnerable to this type of failure. Slopes covered by boulders are subject to rockfall hazard.

2.3 Geologic Hazards in the La Quinta Area

2.3.1 Landslides and Slope Instability

Developments that encroach upon the edge of natural slopes may be impacted by slope failures. Even if a slope failure does not reach the adjacent property, the visual impact will generally cause alarm to homeowners. Although slope failures tend to affect a relatively small area (as compared to an earthquake or major flood), and are generally a problem for only a short period of time, the dollar losses can be high. Homeowner's insurance policies typically do not cover land slippage, and this can add to the anguish of the affected property owners.

A significant portion of the General Plan area encompasses hillside terrain. Hillside areas within and adjacent to La Quinta are part of the Santa Rosa Mountains National Monument and are designated as open space. However, because there is development present at the base of the steep slopes, slope stability remains a potential hazard.

2.3.1.1 *Types of Slope Failures*

Slope failures occur in a variety of forms, and there is usually a distinction made between **gross failures** (sometimes also referred to as "global" failures) and **surficial failures**. Gross failures include deep-seated or relatively thick slide masses, such as landslides, whereas surficial failures can range from minor soil slips to destructive mud or debris flows. Failures can occur on natural or man-made slopes. Most failures of man-made slopes occur on older slopes built at slope gradients steeper than those allowed by today's grading codes. Although infrequent, failures can also occur on newer, graded slopes, generally due to poor engineering or poor construction. Furthermore, slope failures often occur as elements of interrelated natural hazards in which one event triggers a secondary event, such earthquake-induced landsliding, fire-flood sequences, and storm-induced mudflows.

Gross Failures

Landslides are movements of relatively large landmasses, either as nearly intact bedrock blocks, or as jumbled mixes of bedrock blocks, fragments, debris, and soils. Landslide materials are commonly porous and very weathered in the upper portions and along the margins of the slide. They may also have open fractures and joints. The head of the slide may have a graben (pull-apart area) that has been filled with soil, bedrock blocks and fragments.

The potential for slope failure is dependent on many factors and their interrelationships. Some of the most important factors include slope height, slope steepness, shear strength and orientation of weak layers in the underlying geologic unit, as well as pore-water pressures. Joints and shears, which weaken the rock fabric, allow water to infiltrate the rock mass. This in turn results in increased and deeper weathering of the rock, increased pore pressures, increased plasticity of weak clays that may be present in the rock, and increased weight of the landmass. Geotechnical engineers combine these factors in calculations to determine if a slope meets a minimum safety standard. The generally accepted standard is a factor of safety of 1.5 or greater (where 1.0 is equilibrium, and less than 1.0 is failure). Natural slopes, graded slopes, or graded/natural slope combinations must meet these minimum engineering standards where they have the potential to impact planned homes, subdivisions, or other types of developments. Slopes adjacent to areas where the risk of economic losses from landsliding is small, such as parks and roadways, are sometimes allowed a lesser factor of safety, at the discretion of the local reviewing agency.

The rock types in the La Quinta General Plan Area are generally resistant to landsliding; however, several "rock avalanche" landslides have been mapped in the mountains above the city (see Plate 2-2). Depending on their fracture pattern, foliation, and weathering, these rocks may become susceptible to slope failure if they are cut to very steep gradients, such as are commonly found in highway roadcuts.

Surficial Failures
Surficial failures are too small to map at the scale used in Plate 2-2, however they may be present locally in hillside areas, typically occurring in drainage swales and in the accumulated sediments and deeply weathered bedrock near the base of steep slopes. Surficial failures generally occur throughout the mountainous areas during winters of particularly heavy and/or prolonged rainfall. The most common types of surficial instability are described below.

Soil slip failures are generated by strong winter storms, and are widespread in mountainous areas, particularly after winters with prolonged and/or heavy rainfall. Failures occur on canyon sideslopes, and in soils that have accumulated in swales, gullies and ravines. Slope steepness has a strong influence on the development of soil slips, with most slips occurring on slopes having gradients between about 27 and 56 degrees (Campbell, 1975). *Slopes within this range of gradients are present in the higher hills and mountains within and above the La Quinta General Plan Area.*

Debris flows are the most dangerous and destructive of all types of slope failure. A debris flow (also called mudflow, mudslide, and debris avalanche) is a rapidly moving slurry of water, mud, rock, vegetation and debris. Larger debris flows are capable of moving trees, large boulders, and even cars. This type of failure is especially dangerous as it can move at speeds as fast as 40 feet per second, is capable of crushing buildings, and can strike with very little warning. As with soil slips, the development of debris flows is strongly tied to exceptional storm periods of prolonged rainfall. Failure typically occurs during an intense rainfall event, following saturation of the soil by previous rains.

A debris flow most commonly originates as a soil slip in the rounded, soil-filled "hollow" at the head of a drainage swale or ravine. The rigid soil mass is deformed into a viscous fluid that moves down the drainage, incorporating into the flow additional soil and vegetation scoured from the channel. Debris flows also occur on canyon walls, often in soil-filled swales that do not have topographic expression. The velocity of the flow depends on the viscosity, slope gradient, height of the slope, roughness and gradient of the channel, and the baffling effects of vegetation. Even relatively small amounts of debris can cause damage from inundation and/or as a result of crashing into a structure (Ellen and Fleming, 1987; Reneau and Dietrich, 1987). Recognition of this hazard led FEMA to modify its National Flood Insurance Program to include inundation by "mudslides."

NOTES:

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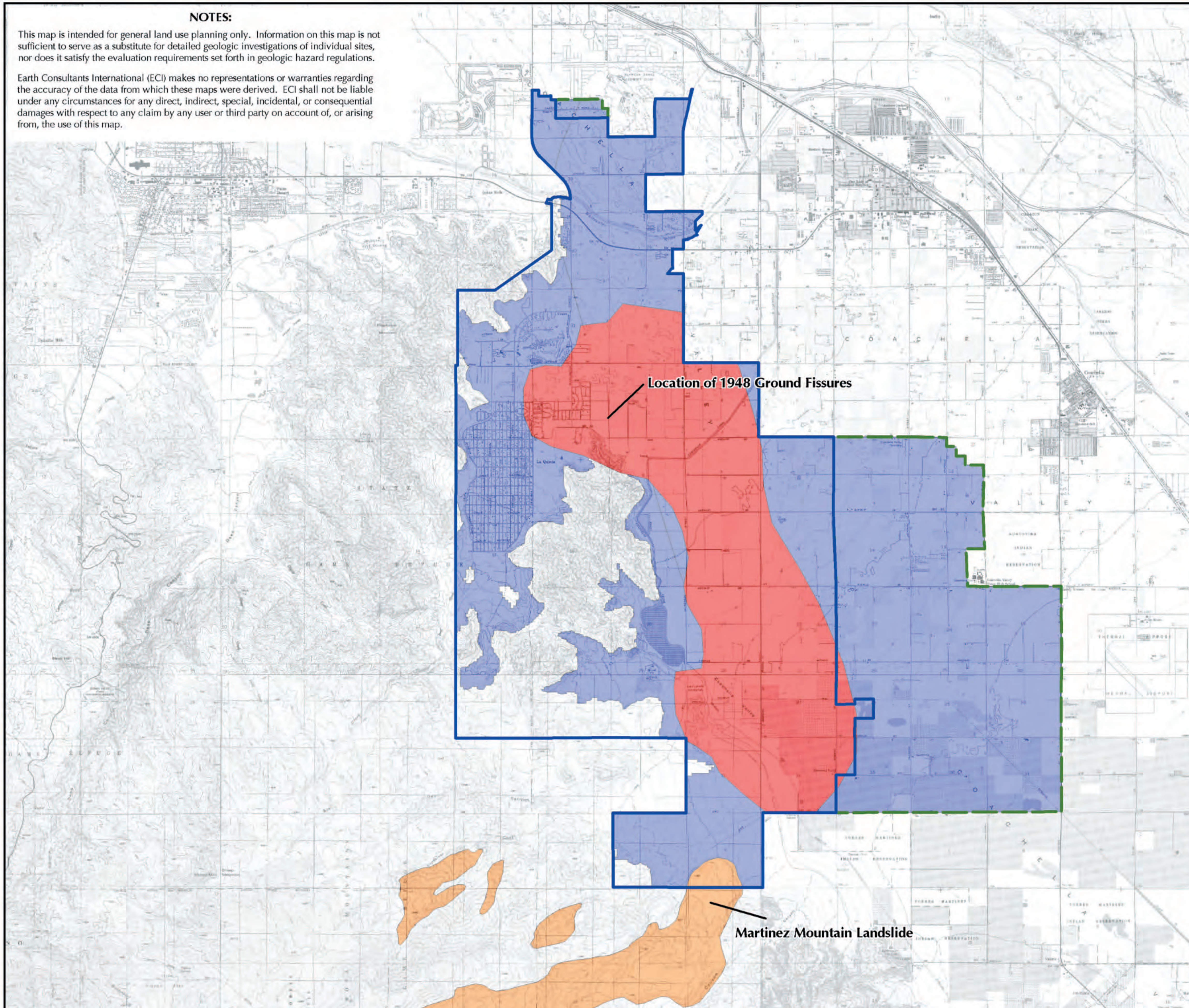

Mapped Slope Failures and Subsidence Zones

La Quinta, California

Explanation

Subsidence

- Documented Subsidence
- Susceptible

Landslides

- Mapped Landslide, Dibblee (2008)

- La Quinta City Boundary
- La Quinta Sphere of Influence

N S W E

7000 0 7000

Feet

2000 0 2000

Meters

Scale: 1:84,000

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Sources: Modified from Riverside County General Plan (Earth Consultants Int., 2000), Dibblee (2008), and Sneed and Brandt (2007).

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Plate 2-2

Watersheds that have been recently burned typically yield greater amounts of soil and debris than those that have not burned. Erosion rates during the first year after a fire are estimated to be 15 to 35 times greater than normal, and peak discharge rates range from two to 35 times higher. These rates drop abruptly in the second year, and return to normal after about five years (Tan, 1998). In addition, debris flows in burned areas can develop in response to small storms and do not require a long period of antecedent rainfall. These kinds of flows are common in small gullies and ravines during the first rains after a burn, and can become catastrophic when a severe burn is followed by an intense storm season (Wells, 1987). A recent example is the debris flows that impacted several communities at the base of the portion of the Los Angeles National Forest that burned during the Station Fire of August and September 2009. The debris flows, which occurred in February 2010, following several intense rainstorms, severely damaged more than 40 homes and many cars were swept by the mud- and debris-laden water.

Within the General Plan area, locations that are most susceptible to debris flows are those properties at the base of moderate to steep slopes, or at the mouths of small to large drainage channels.

Rockfalls are free-falling to tumbling masses of bedrock that have broken off steep canyon walls or cliffs. The debris from repeated rockfalls typically collects at the base of extremely steep slopes in cone-shaped accumulations of angular rock fragments called talus. Rockfalls can happen wherever fractured rock slopes are oversteepened by stream erosion or man's activities.

The bedrock common to the area's hillsides weathers into large boulders that perch precariously on slopes, posing a rockfall hazard to areas adjacent to and below these slopes. A rockfall or rockslide may happen suddenly and without warning, but is more likely to occur in response to earthquake-induced ground shaking, during periods of intense rainfall, or as a result of man's activities, such as grading and blasting. *As discussed in Chapter 1, rockfall hazard in the La Quinta General Plan area is largely restricted to properties at or near the base of boulder-covered slopes.*

2.3.1.2 *Mitigation of Slope Instability in Future Development*

Careful land management in hillside areas can reduce the risk of economic and social losses from slope failures. This generally includes land use zoning to restrict development in unstable areas, grading codes for earthwork construction, geologic and soil engineering investigation and review, construction of drainage structures, and if warranted, placement of warning systems. Other important factors are risk assessments (including susceptibility maps), a concerned local government, and an educated public.

The Municipal Code for the City of La Quinta includes regulations and standards for development in hillside areas (Title 9: Zoning, Chapter 9.140: Supplemental Special Purpose Regulations, Section 9.140.040: HC Hillside Conservation Regulations). The intent of this regulation is to: 1) protect the health and safety of the public; 2) protect and preserve existing landforms, drainage patterns, natural ridgelines and rock outcrops, scenic vistas, native vegetation and wildlife habitat; 3) discourage mass grading and terracing; 4) encourage variety in design; and 5) mitigate slope instability, erosion, and sedimentation by requiring soils reports, and where necessary, engineered drainage facilities.

In the city of La Quinta all hillsides are zoned as open space and included in the HC hillside conservation overlay district. The Code defines hillside areas as those with a slope of 20% or greater and includes both mountain slopes and alluvial fans not protected by flood control structures. The Code allows certain uses on alluvial fans sloping less than 20%, including single-family residences, however these are subject to various guidelines, as well as planning and engineering reviews by the City. For slopes steeper than 20%, uses are restricted to trails, and under some conditions, access roads.

For the unincorporated areas of the General Plan, Riverside County Ordinances provide similar standards and guidelines for growth and development, in addition to providing a basis for county-wide planning and construction of public facilities such as drainage control. The ordinances address zoning, permitting, grading, and investigation requirements for areas subject to potential geologic problems, including slope instability.

Soils and geology reports for hillside areas, which are required by both the City and the County, should include a geotechnical evaluation of any slope that may impact the future use of the property, as well as any impact to adjacent properties. This includes existing slopes that are to remain natural, and any proposed graded slopes. This type of investigation typically includes borings and/or test pits to collect geologic data and soil samples, laboratory testing of the soil samples to determine soil strength parameters, and engineering calculations. Numerous soil-engineering methods are available for stabilizing slopes that pose a threat to development. These methods include designed buttresses (replacing the weak portion of the slope with engineered fill); reducing the height of the slope; designing the slope at a flatter gradient; and adding reinforcements to fill slopes such as soil cement or layers of geogrid (a tough polymeric net-like material that is placed between the horizontal layers of fill). Most slope stabilization methods include a subdrain system to prevent excessive ground water (typically landscape water) from building up within the slope area. If it is not feasible to mitigate the slope stability hazard, building setbacks are typically imposed.

For debris flows, assessment of this hazard for individual sites should focus on structures located or planned in vulnerable positions. This generally includes canyon areas; at the toes of steep, natural slopes; and at the mouth of small to large drainage channels. Mitigation of soil slips and debris flows is usually directed at containment (debris basins), or diversion (impact walls, deflection walls, diversion channels, and debris fences). A system of baffles may be added upstream to slow the velocity of a potential debris flow. Other methods may include avoidance by restricting habitable structures to areas outside of the potential debris flow path.

There are numerous methods for mitigating rockfalls. Choosing the best method depends on the geological conditions (i.e., slope height, steepness, fracture spacing, foliation orientation), safety, type and cost of construction repair, and aesthetics. A commonly used method is to regrade the slope. This ranges from locally trimming hazardous overhangs, to completely reconfiguring the slope to a more stable condition, possibly with the addition of benches to catch small rocks. Another group of methods focuses on holding the fractured rock in place by draping the slope with wire mesh, or by installing tensioned rock bolts, tie-back walls, or even retaining walls. A third type of mitigation includes catchment devices at the toe of the slope, such as ditches, walls, or combinations of both. Designing the width of the catchment structure requires analysis of how the rock will fall. For instance, the slope gradient and roughness of the slope determines if rocks will fall, bounce, or roll to the bottom (Wyllie and Norrish, 1996).

Temporary slope stability is also a concern, especially where earthwork construction is taking place next to existing improvements. Temporary slopes are those made for slope stabilization backcuts, fill keys, alluvial removals, retaining walls, and underground utility lines. The risk of slope failure is higher in temporary slopes because they are generally cut at a much steeper gradient. In general, temporary slopes should not be cut steeper than 1:1 (horizontal:vertical), and depending on actual field conditions, flatter gradients or shoring may be necessary. The potential for slope failure can also be reduced by cutting and filling large excavations in segments, and not leaving temporary excavations open for long periods of time. The stability of large temporary slopes should be geotechnically analyzed prior to construction, and mitigation measures provided as needed.

2.3.1.3 *Mitigation of Slope Instability in Existing Development*

There are a number of options for the management of potential slope instability where development has already taken place. Implementation of these options should reduce the hazard to an acceptable level, including reducing or eliminating the potential for loss of life or injury, and reducing economic loss to tolerable levels. Mitigation measures may include:

- Protecting existing development and population where appropriate by physical controls such as improved drainage, slope-geometry modification, protective barriers, and retaining structures;
- Posting warning signs in areas of potential slope instability;
- Encouraging homeowners to install landscaping consisting primarily of drought-resistant, preferably native vegetation that helps stabilize the hillsides;
- Incorporating recommendations for potential slope instability into geologic and soil engineering reports for building additions and new grading; and
- Providing public education on slope stability, including the importance of maintaining drainage devices and avoiding heavy irrigation. U.S. Geological Survey Fact Sheet FS- 071-00 (May, 2000) and California Geological Survey Note 33 (March, 2004) provide public information on landslide and mudslide hazards. Both of these are available on the World Wide Web (see Appendix A).

2.3.2 Compressible Soils

Compressible soils are typically geologically young, unconsolidated sediments of low density that may compress under the weight of proposed fill embankments and structures. The settlement potential and the rate of settlement in these sediments can vary greatly, depending on the soil characteristics (texture and grain size), natural moisture and density, thickness of the compressible layer(s), the weight of the proposed load, the rate at which the load is applied, and drainage.

In the La Quinta General Plan area, compressible soils are most likely to occur in the valley, where young deposits are present (see Plate 2-1). This would generally include the *modern and prehistoric floodplains of the major drainages, such as the Whitewater River, wind-blown deposits, and the upper part of the young alluvium that blankets the valley floor. Compressible soils are also commonly found in hillside areas, typically in canyon bottoms, swales, and at the base of natural slopes. Although the older alluvial fan deposits in the La Quinta area are relatively dense, the upper few feet, which are commonly weathered and/or disturbed, are typically compressible. Deep fill embankments, generally those more than about 60 feet deep, will also compress under their own weight.*

2.3.2.1 *Mitigation of Compressible Soils*

When development is planned within areas that contain potentially compressible soils, a geotechnical analysis is required to confirm whether or not this hazard is present. The analysis should consider the characteristics of the soil column in that specific area, and also the load of any proposed fills and structures that are planned, the type of structure (i.e. a road, pipeline, or building), and the local groundwater conditions. Removal and recompaction of the near-surface soils is generally the minimum that is required. Deeper removals may be needed for heavier loads, or for structures that are sensitive to minor settlement. Based on the location-specific data and analyses, partial removal and recompaction of the compressible soils are sometimes performed, followed by settlement monitoring for a number of months after additional fill has been placed, but before buildings or infrastructure are constructed. Similar methods are used for deep fills. In cases where it is not feasible to remove the compressible soils, buildings can be supported on specially engineered foundations that may include deep caissons or piles.

2.3.3 Collapsible Soils

Hydroconsolidation or soil collapse typically occurs in recently deposited sediments that accumulated in an arid or semi-arid environment. Sediments prone to collapse are commonly associated with alluvial fan and debris flow sediments deposited during flash floods. These deposits are typically dry and contain minute pores and voids. The soil particles may be partially supported by clay, silt or carbonate bonds. When saturated, collapsible soils undergo a rearrangement of their grains and a loss of cementation, resulting in substantial and rapid settlement under relatively light loads. An increase in surface water infiltration, such as from irrigation, or a rise in the groundwater table, combined with the weight of a building or structure, can initiate rapid settlement and cause foundations and walls to crack. Typically, differential settlement of structures occurs when landscaping is heavily irrigated in close proximity to the structure's foundation.

The young alluvial and wind-deposited sediments in the La Quinta General Plan area may be locally susceptible to this hazard due to their low density, rapid deposition in the desert environment, and the generally dry condition of the upper soils.

2.3.3.1 *Mitigation of Collapsible Soils*

The potential for soils to collapse should be evaluated on a site-specific basis as part of the geotechnical studies for development. If the soils are determined to be collapsible, the hazard can be mitigated by several different measures or combination of measures, including excavation and recompaction, or pre-saturation and pre-loading of the susceptible soils in place to induce collapse prior to construction. After construction, infiltration of water into the subsurface soils should be minimized by proper surface drainage design, which directs excess runoff to catch basins and storm drains.

2.3.4 Expansive Soils

Fine-grained soils, such as silts and clays, may contain variable amounts of expansive clay minerals. These minerals can undergo significant volumetric changes as a result of changes in moisture content. The upward pressures induced by the swelling of expansive soils can have significant harmful effects upon structures and other surface improvements.

The valley portion of the La Quinta General Plan area is underlain by sediments that are composed of alluvial sand and gravel interlayered with fine-grained lakebed deposits (silts and clays). Consequently, after site grading, the expansion characteristics of the soils at finish grade can be highly variable. Pedogenic soil profiles that have developed on older alluvial fan deposits as a result of weathering are commonly clay-rich and probably fall in the moderately expansive range.

The rock that forms the hills and mountains generally has low expansion characteristics, however sheared zones within the rock may contain clays with expansive minerals.

In some cases, engineered fills may be expansive and cause damage to improvements if such soils are incorporated into the fill near the finished surface.

2.3.4.1 *Mitigation of Expansive Soils*

The best defense against this hazard in new developments is to avoid placing expansive soils near the surface. If this is unavoidable, building areas with expansive soils are typically "presaturated" to a moisture content and depth specified by the soil engineer, thereby "pre-swelling" the soil prior to constructing the structural foundation or hardscape. This method is often used in conjunction with stronger foundations that can resist small ground movements without cracking. Good surface drainage control is essential for all types of improvements, both new and old. Property owners should be educated about the importance of maintaining relatively constant moisture levels in their landscaping. Excessive watering, or alternating wetting and drying, can result in distress to improvements and structures.

2.3.5 Corrosive Soils

Corrosive soils can, over time, cause extensive damage to buried metallic objects, commonly impacting such things as buried pipelines (such as water mains), and even affecting steel elements within foundations. The electrochemical and bacteriological processes that take place between the soil and the buried structure are complex and depend on a number of factors involving the structure type and certain soil characteristics. For instance, the type, grade, length, and size of the piping, as well as the materials used in the pipe connections, may control the electrochemical reactions that will take place between the pipes and the surrounding soil, and different soils may react differently. For soils, the most common factor used in identifying the potential for corrosion is electrical resistivity. Soils with low resistivity are especially susceptible to corrosion reactions. Other soil characteristics that increase the risk of corrosion to metals are low pH (acidic soils), wet soils, high chloride levels, low oxygen levels, and the presence of certain bacteria.

Soils with high concentrations of soluble sulfates are not directly corrosive to metals, however the presence of sulfate-reducing bacteria in the soil may cause sulfates to convert to sulfides, which are compounds that do increase the risk for corrosion. If the concentration of soluble sulfates is high enough, the soil will be corrosive to concrete.

2.3.5.1 *Mitigation of Corrosive Soils*

Corrosion testing is an important part of geotechnical investigations. Onsite soils, as well as any imported soils, are typically tested in the laboratory for resistivity, pH, chloride, and sulfates. For treatment of high sulfate content, special cement mixes and specified water contents are typically used for concrete that will be in contact with the soil. For corrosion of metals, there are a number of procedures used to protect the structure, including cathodic protection, coatings such as paint or tar, or wrapping with protective materials. As mentioned above, the corrosion processes are complex; consequently, the site-specific recommendations must be provided by an engineer who is a corrosion specialist.

2.3.6 Ground Subsidence

Ground subsidence is the gradual settling or sinking of the ground surface with little or no horizontal movement. Most ground subsidence is man-induced. In the areas of California where ground subsidence has been reported (such as the San Joaquin Valley, Coachella Valley, and Wilmington), this phenomenon is most commonly associated with the extraction of fluids (water and/or petroleum) from sediments below the surface. Less commonly, ground subsidence can also occur as a response to natural forces such as earthquake movements. Earthquakes have caused abrupt regional elevation changes in excess of one foot across faults. For instance, the Imperial Valley earthquake of 1979 resulted in ground subsidence of approximately 15 inches on the east side of the Imperial fault (Sharp and Lienkaemper, 1982).

Ground-surface effects related to regional subsidence can include earth fissures, sinkholes or depressions, and disruption of surface drainage. Damage is generally restricted to structures sensitive to slight changes in elevations, such as canals, levees, underground pipelines, and drainage courses; however, significant subsidence can result in damage to wells, buildings, roads, railroads, and other improvements. Subsidence due to the overdraft of groundwater supplies can also result in the permanent loss of aquifer storage capacity. Subsidence has largely been brought under control in affected areas by careful management of local water supplies, including reducing pumping of local wells, importing water, and use of artificial recharge (Johnson, 1998; Stewart et al., 1998).

The Coachella Valley is filled with as much as 14,000 feet of sediments, with the upper 2,000 feet defined as water-bearing deposits. As discussed in the previous chapter, the area is tectonically active, and regional subsidence over the last several millions of years is responsible for the great thickness of alluvial deposits along the valley floor. Nevertheless, the rate of subsidence in some areas appears to have accelerated recently, at rates too great to be accounted for solely by tectonics. Increased groundwater pumping coincident with these rapid rates of subsidence suggests that groundwater extraction is causing the subsidence that has been reported locally in the Coachella Valley. Recognizing that significant subsidence in the area could pose a major environmental constraint, several agencies (including the U.S. Geological Survey, and the Coachella Valley Water District) are currently devoting resources to the study and mitigation of this potential hazard.

Regional subsidence related to groundwater withdrawal was first suspected in the Coachella Valley when ground fissuring developed suddenly in the city of La Quinta in 1948 (see Plate 2-2). The fissures occurred after nearly 30 years of intense groundwater pumping for agricultural, municipal and domestic purposes. Water levels declined as much as 50 feet between the early 1920s and the late 1940s, before imported water from the Colorado River became the area's main water source. Once surface water from the Coachella Canal was introduced in 1949, pumping of ground water decreased, and between 1950 and the 1970s, groundwater levels actually recovered throughout most of the valley. Some of the basin recharge was also attributed to the leakage from unlined water canals. Since the late 1970s, however, the demand for water has exceeded the deliveries of imported surface water, and groundwater levels have again been declining as a result of increased pumping. By 1996, water levels in some wells had dropped 50 to 100 feet, to all-time historical lows.

Recognizing that these observed declines in water level had the potential to induce new or renewed land subsidence in the area, the U.S. Geological Survey established in 1996 a precise geodetic network to monitor land subsidence in the lower Coachella Valley. This network of monuments extended from the Salton Sea on the south to just northwest of Indio (Ikehara et al., 1997). The study compared elevation measurements made in 1996 using Geographic Positioning System (GPS) technology with elevation survey data collected by several agencies over several years, dating back to 1936. Because the methods and geographic scales used varied from agency to agency, there are substantial error bars on the results, but the data indicate that between 1936 and 1996, the lower Coachella Valley subsided by as much as 0.5 feet (±0.3 feet) (Ikehara et al., 1997; Sneed et al., 2001).

Where data were available, historical subsidence was plotted over time and compared to water level changes in nearby wells. In general, subsidence occurred during periods of water level decline, and rebound occurred during intervening periods of water level recovery. Since the timing of the subsidence measurements corresponds with water level declines, land subsidence appears to be occurring in response to groundwater pumping. Water levels began declining below their previously recorded low levels in the early 1990s. Researchers believe that most of the subsidence measured in 1996 had probably just occurred in the last few years prior to the survey. Rapid rates of subsidence over a relatively short period of time are suggested by a study conducted in 1998, when 14 of the 17 original monuments were re-surveyed. The measurements indicate that between 1996 and 1998, vertical changes (subsidence) in the land surface elevation of between 0.04 to 0.22 feet (±0.13 feet) occurred locally.

Since a large portion of the Coachella Valley was not covered in the first study, new technology referred to as Interferometric Synthetic Aperture Radar (InSAR) was used to extend the study area northwesterly, to the Palm Springs/Palm Desert area. InSAR uses differences in reflected radar signals acquired at different times to measure ground-surface deformations. [This method has been used successfully in the last few years to study changes in the land and built environment resulting from earthquakes, volcanic activity, and even warfare]. The InSAR-generated maps reviewed by Sneed et al. (2001) show three areas that appear to have subsided between May 7, 1996 and September 30, 1998: in the Rancho Mirage/Palm Desert area, in the Indian Wells area, and southeast of the modern

Lake Cahuilla. The Rancho Mirage/Palm Desert area that appears to have subsided extends from about Country Club Drive on the north, to Fred Waring Drive on the south, and between Highway 111 and the San Jacinto Mountains on the west, to Portola Avenue on the east. Subsidence of as much as 0.23 feet was measured in the southwestern portion of this area. The subsidence area in Rancho Mirage/Palm Desert coincides with an area of substantial groundwater development, where more than 70 production wells produced about 170,000 acre-feet of water during the 1996-98 period (Sneed et al., 2001).

The results of a third study were released in 2002, covering the period between 1998 and 2000. During this time, four additional GPS stations were placed in the valley (including one in the Rancho Mirage/Palm Desert area). Four InSAR images (two pairs) were combined to evaluate ground elevation changes between two time periods as follows: 1) June 1998 to June 1999, and 2) November 1999 to October 2000. The InSAR data indicate that subsidence was still occurring in the three areas previously identified, plus in a new area near La Quinta. The Rancho Mirage/Palm Desert subsidence area (with a 0.2 feet drop in the surface elevation during this period) coincides with or is near areas where groundwater levels have again declined, in some cases to new lows from their recorded histories (Sneed et al., 2002). The U.S. Geological Survey team recommended that monitoring for subsidence be continued in the area. However, given that the rates of subsidence appear to be small compared to the GPS measurement error, the team indicated that GPS surveys need not be conducted on an annual basis.

The most current study released by the U.S. Geological Survey reports subsidence rates have increased two to four times since the year 2000 in Palm Desert, Indian Wells, and La Quinta. Water levels in wells within or near the subsiding areas fluctuated seasonally and declined annually between 1996 and 2005. In fact some 2005 water levels were at the lowest levels in their recorded histories. The report concluded that due to the localized character of the subsidence, as well as the coincident areas of declining water levels and subsidence, some aquifer compaction may be taking place. Although groundwater pumping is the most likely cause of the subsidence, it could also be due to tectonic activity in the valley (Sneed and Brandt, 2007).

Permanent (irreversible) subsidence can occur if ground water is removed from clay and silt layers in the underlying aquifer. This later scenario has heavily impacted the Antelope Valley where surface fissures or cracks in the land surface have been reported. The cracks, which have measured as much as 1,300 feet long, 6 feet wide, and 13 feet deep, have caused substantial damage to runways, roads, wells, pipelines, and other structures. With the exception of the cracks observed in the La Quinta area in 1948, no cracks or fissures have been reported in the Coachella Valley. There is however, the potential for fissuring to develop if subsidence as a result of groundwater pumping continues or increases in the area. It is not clear why ground fissures developed in the La Quinta area, but the area where they developed, near the intersection of Avenue 52 and Adams Street, is near the margin of the Coachella Valley, at the base of the Santa Rosa Mountains. While subsidence typically occurs throughout an overdrafted valley, differential displacement and fissures are generally manifested at or near the valley margin. Therefore, if subsidence continues in the lower Coachella Valley, damage to structures as a result of regional subsidence would be expected to be greatest at the valley margin.

2.3.6.1 *Mitigation of Ground Subsidence*

Prevention of subsidence requires a regional approach to groundwater conservation and recharge. Conservation efforts will be more than offset by the rapid growth of the region and the heavy water requirements of golf courses (±8 acre-feet per acre per year) unless water consumption is diligently managed. Some measures that can be implemented to manage subsidence include:

- Increase use of reclaimed water, storm water, or imported water;
- Implement artificial recharge programs (some of this is already being done, with percolation ponds near Palm Springs and recharge ponds near Desert Hot Springs);
- Determine the safe yields of groundwater basins, so that available supplies can be balanced with extraction;
- Monitor the groundwater and basin conditions;
- Establish a monitoring program to detect changes in ground elevations above producing aquifers;
- Protect groundwater quality;
- Reduce long-term water demand with specific programs of water conservation; and
- Acquire additional imported water supplies, and encourage water conservation through public education.

Mitigation measures are expected to be difficult to implement; however, the Coachella Valley Water Management Program (adopted by the Coachella Valley Water District [CVWD] in October, 2002) addresses many of these issues, including artificial recharge with water from the Colorado River Aqueduct, conservation programs, utilization of canal and recycled water (i.e. for agriculture and golf courses), the inclusion of water efficient plumbing in new construction, and the use of more efficient irrigation practices, especially for high quantity users such as farmers, golf courses, and large developments. The goal of the program is reduce water consumption in the valley even with the expected population increases. In 2003, the Coachella Valley Water District adopted a landscape model ordinance that calls for the use of water-efficient vegetation in new and remodeled landscaping. The City of La Quinta, in conjunction with the CVWD, has created a city-wide Landscape Water Management Program aimed at reducing landscape water usage and eliminating sprinkler runoff. The program includes water audits, drought-resistant landscaping, drip irrigation systems, and public education. Similar landscape ordinances and programs should be considered by all desert communities, as the need for more efficient use of water will only increase as the population in this area increases.

2.3.7 Erosion

Erosion, runoff, and sedimentation are influenced by several factors, including climate, topography, soil and rock types, and vegetation. The topographic relief between the valley and the adjacent mountains makes erosion and sedimentation an important issue for La Quinta. The fractured condition of the bedrock forming the mountains, combined with rapid geologic uplift and infrequent but powerful winter storms leads to high erosion rates. Further, erosion can increase significantly when mountain slopes are denuded by wildfires. Winter storms that follow a season of mountain wildfires can transport great volumes of sediment onto the low-lying areas below.

In the La Quinta General Plan area, the unconsolidated sediments in the canyon bottoms and valley floors are generally the most susceptible to erosion. Natural erosion processes, even on more consolidated sediments, are often accelerated through man's activities – whether they be agricultural or land development. Grading increases the potential for erosion and sedimentation by removing protective vegetation, altering natural drainage patterns, compacting the soil, and constructing cut and fill slopes that may be more susceptible to erosion than slopes in their natural condition. Developments also reduce the surface area available for infiltration, leading to increased flooding and sedimentation downstream of the project.

2.3.7.1 *Mitigation of Erosion*

Erosion will have an impact on those portions of La Quinta located above and below natural and man-made slopes. Hilltop homes or structures above natural slopes should not be permitted at the head of steep drainage channels or gullies without protective measures against headward erosion of the gully. Structures placed near the base of slopes or near the mouths of small canyons, swales, washes, and gullies will need protection from sedimentation. Developments in the valley that are adjacent to natural drainage channels should be adequately set back from eroding channel banks. Alternatively, modification of the channel to reduce erosion should be included in the project design. Although development is generally not present and not permitted within canyons and major drainage channels, roadways and utility lines, out of necessity, must sometimes cross these areas and will need protection from erosion and sedimentation.

Mitigation of erosion and sedimentation typically includes structures to slow down stream velocity, such as check dams and drop structures, devices to collect and channel the flow, catchment basins, and elevating structures above the toes of the slopes. Diversion dikes, interceptor ditches, swales, and slope down-drains are commonly lined with asphalt or concrete, however ditches can also be lined with gravel, rock, decorative stone, or grass.

There are many options for protecting manufactured slopes from erosion, such as terracing slopes to minimize the velocity attained by runoff, the addition of berms and v-ditches, and installing adequate storm drain systems. Other measures include establishing protective vegetation, and placing mulches, rock facings (either cemented on non-cemented), gabions (rock-filled galvanized wire cages), or building blocks with open spaces for plantings on the slope face. All slopes within developed areas should be protected from concentrated water flow over the tops of the slopes by the use of berms or walls. All ridge-top building pads should be engineered to direct drainage away from slopes.

Temporary erosion control measures must be provided during the construction phase of a development, as required by local building codes and ordinances, as well as State and Federal stormwater pollution regulations. In addition, permanent erosion control and clean water runoff measures are required for new developments. These measures might include desilting basins, percolation areas to cleanse runoff from the development, proper care of drainage control devices, appropriate irrigation practices, and rodent control. Erosion control devices should be field-checked following periods of heavy rainfall to assure they are performing as designed and have not become blocked by debris.

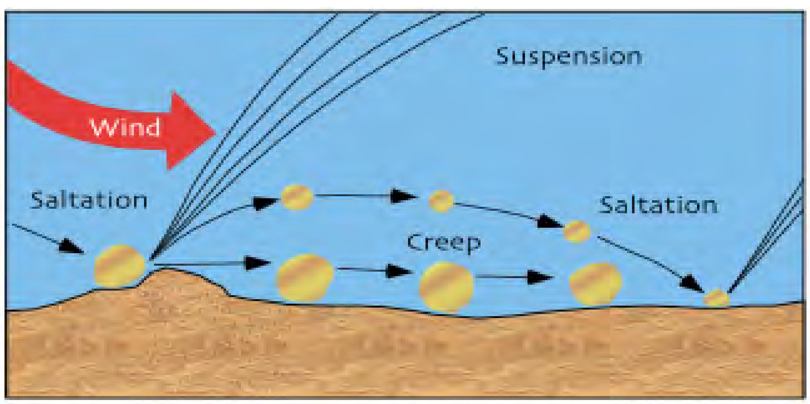
Both the City of La Quinta and the County of Riverside require plans be developed for both temporary and permanent erosion control in new projects. Construction must comply with the project's Storm Water Pollution Prevention Plan and Best Management Practices, which are part of the site's grading plans. The goal is to minimize or restrict the release of runoff and sediment from the site, as well as debris or potential pollutants.

2.3.8 Wind-Blown Sand

Wind erosion is a serious environmental problem attracting the attention of many across the globe. It is a common phenomenon occurring mostly in flat, bare areas; dry, sandy soils; or anywhere the soil is loose, dry, and finely granulated. Wind erosion damages land and natural vegetation by removing soil from one place and depositing it in another. It causes soil loss, dryness and deterioration of soil structure, nutrient and productivity losses, air pollution, and sediment transport and deposition.

Soil movement is initiated as a result of wind forces exerted against the surface of the ground. For each specific soil type and surface condition, there is a minimum velocity required to move soil particles. This is called the threshold velocity. Once this velocity is reached, the quantity of soil moved is dependent upon the particle size, the cloddiness of the particles, and the wind velocity itself. Suspension, saltation, and surface creep are the three types of soil movement that occur during wind erosion (Figure 2-1). While soil can be blown away at virtually any height, the majority (over 93%) of soil movement takes place at or within one meter (3 feet) of the ground surface.

Figure 2-1: Wind-Induced Soil Movement



Wind-induced soil movement is initiated as a result of wind forces exerted against the surface of the ground, and includes suspension, saltation, and surface creep. Soil can be blown high into the atmosphere; however, most soil movement takes place at or within one meter of the ground surface.

According to El-Aghel (1984), five physical factors determine the distribution and intensity of the wind-blown sand hazard in the Coachella Valley:

- **Orientation of hill and mountain masses**: The major mountain masses bordering the valley have their long axes aligned in a northwest-southeast direction. As a result, these mountains offer little resistance to the free flow of air down the long axis of the Coachella Valley. The narrow San Gorgonio Pass accelerates the wind and improves its ability to pick-up and transport sand.

- **Nature of the bedrock**: The granitic rock that comprises the local mountains readily weathers to grain size categories that are easily transported by wind.

- **Location of the Whitewater River floodplain**: The Whitewater River is the main stream feeding the upper Coachella Valley, and the floodplain is located at the eastern end of San Gorgonio Pass, precisely where wind velocities are the greatest. The river drains much of the adjacent parts of the San Bernardino Mountains, and is the primary source of sand and gravel in the area. During flood events, large quantities of sand and gravel are deposited on the Whitewater floodplain. Studies have shown that increases in the amount of wind-blown sand are related to episodic flooding of the Whitewater River (Sharp, 1964, 1980). For example, a 15-fold increase in wind erosion rates has been noted following heavy flood events (Sharp, 1980). Flood events generally change the character of the Whitewater River drainage from a stony to a sandy appearance. Yet, within a few months of the flooding event, the drainage bottom typically returns to a predominantly stony appearance, as the finer-grained sand is removed from the streambed by the wind, depositing it elsewhere on the valley floor where it becomes a nuisance. Plate 2-3 shows those areas underlain by sediments susceptible to erosion as a result of the strong winds that physically assault the valley portion of the La Quinta General Plan area.

- **Slope of the valley floor**: From the summit of the San Gorgonio Pass, at an elevation of about 1,300 feet, to the Salton Sea, with elevations below sea level, the valley floor slopes without interruption, thereby allowing air to move unhindered down the long axis of the Coachella Valley. The region of greatest blow-sand activity is located down the central axis of the valley, in a region that stretches from eastern Palm Springs to La Quinta.

- **Climate:** The Coachella Valley is a hot dry desert with sparse, widely spaced vegetation. As a result, surficial materials are exposed to wind activity. The precipitation in the adjacent mountains is often short and intense, leading to torrential run-off and considerable detritus deposition on the valley floor.

Wind and wind-blown sand pose an environmental, often destructive, hazard throughout the Coachella Valley, including La Quinta. To measure the effects of the high winds that blow through the valley, in the late 1970s, Caltech investigators conducted several tests near Garnet Hill. The researchers stocked sample plots with 2- to 3-inch-thick lucite rods, common bricks, hard crystalline rock, and gypsum-cement cubes. Then they measured, over several years, the effects of the wind on these artifacts. As a result of wind erosion, one lucite rod was severed, and many samples were eroded up to several centimeters per year. It is no wonder, therefore, that buildings, fences, roads, crops, trees and shrubs can all be damaged by abrasive blowing soil. In some areas, wind-blown sand has actually forced the abandonment of dwellings and subdivided tracts in the central Coachella Valley (Sharp, 1980). Utility poles in the area are frequently armored with sheet metal around the

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

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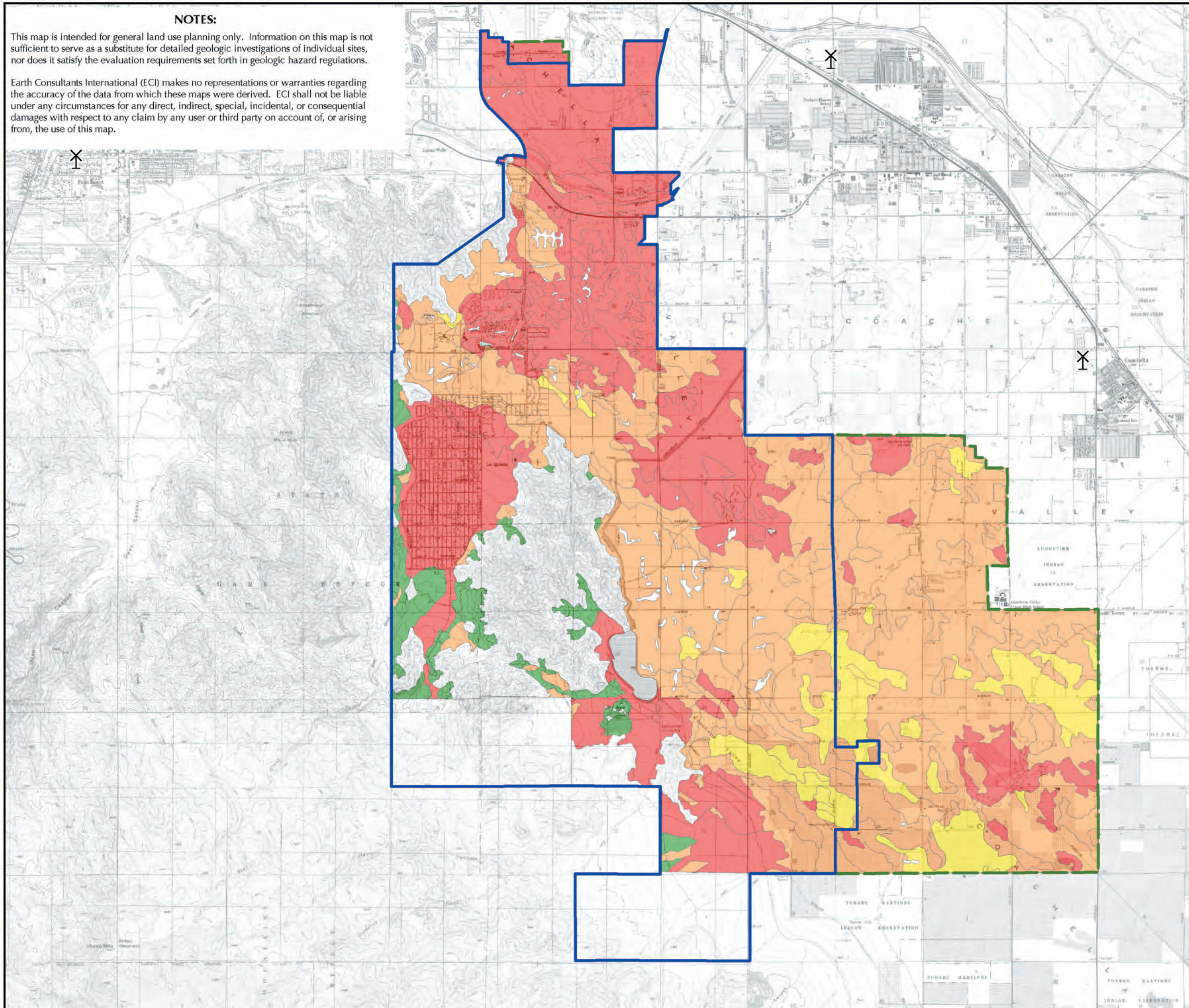


Wind Erosion Susceptibility Map

La Quinta, California

Explanation

Wind Erodibility Rating

- Very high
- High
- Moderate
- Low
- Not rated or not available

Weather Station

La Quinta City Boundary

La Quinta Sphere of Influence

N S W E

6000 0 6000

Feet

2000 0 2000

Meters

Scale: 1:72,000

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997.
Source: modified from Natural Resources Conservation Service Wind Erodibity Group - Riverside County, Coachella Valley Area.

Earth Consultants International

La Quinta 2035 GENERAL PLAN UPDATE

Project Number: 3004
Date: 2010

Plate 2-3

base to help reduce wind erosion. Wind-blown sand has repeatedly caused the closure of roads, costing cities thousands of dollars in cleanup.

The presence of dust particles in the air is also the source of several major health problems. Atmospheric dust causes respiratory discomfort, and may carry pathogens that cause eye infections and skin disorders. Dust storms reduce highway- and air-traffic visibility. Since high winds blow down the axis of the Coachella Valley, the recreational and resort communities that first developed in the Coachella Valley were generally located in areas sheltered from these winds, tucked in coves at the base of the mountains. The older parts of La Quinta are an example of these early developments. However, as the area has grown, development has spread into the central axis of the valley and into the high-wind areas. Rapid development of the Coachella Valley is in part responsible for changes in land use, such as removing native vegetation and building roads and other types of infrastructure, that have led to increases in wind-blown sand across the valley floor. (Grading a site for development results in loose soil that can be readily picked up and transported down-wind.) Recreational land-uses, especially use of off-road vehicles, can also accelerate erosion in the area.

Most of the La Quinta General Plan area is within the active wind erosion zone; only portions of the city near the base of the Santa Rosa Mountains are somewhat protected. The northern part of La Quinta is also underlain by highly erodible sediments (see Plate 2-3).

2.3.8.1 *Mitigation of Wind-Blown Sand*

Mitigation measures that have been used and are used in the area include hedges and other barriers to wind. Increased development in the La Quinta area has had the positive side-effect of reducing the local sand available to be picked up and transported by the wind. This is due to the increasing amount of hardscape (homes, asphalt, and concrete) and vegetation (such as golf courses and ornamental plants) covering the soil and isolating it from the wind.

During grading and construction, however there is the potential for increased amounts of soils available for transport. Therefore, water is typically sprayed at construction sites to reduce dust in the air. On very windy days earthwork construction may be curtailed altogether.

2.4 Summary

The La Quinta General Plan area is highly diverse geologically. This diversity is strongly related to the youthful (in geologic terms) seismic setting of the surrounding region, which includes the ongoing uplift of the San Jacinto/Santa Rosa Mountains to the west and south and tectonic subsidence of the Coachella Valley on the east and north. This, along with the effects of climate, has resulted in a landscape that is complex in geologic processes and hazards. As La Quinta's population grows in the next decades, new development will be needed to meet the demand for homes. When meeting this demand, it is imperative to manage land uses in a responsible way, as development disrupts natural processes, often leading to negative impacts on the environment as well as on the development and adjacent projects. The impacts of land development can be minimized, however, if both site-specific and regional planning elements are recognized and considered, the project incorporates knowledge gained from scientific research in developing and implementing a design appropriate to the area, and protective measures are constructed and maintained for the lifetime of the project.

Most of La Quinta's more densely developed areas are situated in its broad valley. The Santa Rosa Mountains, which will remain as open space, not only form a dramatic backdrop to the area, but also greatly influence the area's climate, geology, and hydrology. These elements combine in various ways to create geologic hazards, as well as benefits to the community. Hazards that have the greatest impact on the General Plan area are summarized below.

Slope instability is a potential hazard where development has encroached up to the base of the mountains. The rock types forming the local mountains are generally resistant to landsliding, so future slope failures are more likely to consist of surficial failures and erosion of sandy geologic materials. Such failures typically occur during exceptional and/or prolonged rainfall, and may manifest as mud or debris flows. Rockfall is a hazard near the base of the mountains, in areas where the bedrock forms bouldery outcrops. Rockfalls or rockslides are more likely to occur as a result of earthquake-induced ground shaking, posing a threat to structures and passing motorists.

Potentially compressible and/or collapsible soils underlie a significant part of the valleys and canyons, typically where geologically young sediments have been deposited, such as young alluvial fans, washes, and canyon bottoms. These are generally young sediments of low density with variable amounts of organic materials. Under the added weight of fill embankments or buildings, these sediments can settle, causing distress to improvements.

Some of the geologic units, primarily in that portion of the valley that was once occupied by Ancient Lake Cahuilla, have fine-grained components that are likely to be moderately to highly expansive. These materials may be present at the surface or may be exposed by grading activities. Man-made fills can also be expansive, depending on the soils used to construct them.

Sediments in the valley areas may be corrosive to metallic objects, such as pipelines, that are in contact with the soil. All soils should be tested for corrosion potential, with mitigation measures developed by a corrosion engineer where needed.

Regional ground subsidence from groundwater withdrawal is a hazard that can reduced or prevented by aggressive water management, the use of recycled water, the continued development of new water sources, continuing public education, the widespread use of drought-tolerant plants in landscaping, and the implementation and enforcement of stringent water conservation measures, especially during droughts. The City should also consider requiring new subdivisions or commercial developments to install the infrastructure for water recycling, so that these sites can be connected to recycled water mains as they become available. With the expected increase in population, water shortage is one of the most serious challenges ahead. Overdraft of the aquifers underlying La Quinta could result in permanent ground subsidence, with resultant negative impact on the area's environmental quality.

Because of the topographic relief in and around La Quinta, erosion and sedimentation are inherently significant elements of the natural setting. Land development can have adverse impacts on these elements by altering the natural processes, topography, and protective vegetation, in addition to reducing the area of natural infiltration. This in turn can lead to damage from increased flooding, erosion, and sedimentation in other areas, typically downstream. Erosion and sedimentation are also important considerations on a site-specific basis, with respect to developments adjacent to slopes and drainage channels. These issues are not only critical during the design of a project, but also during construction and during the long-term maintenance of the developed site.

Damage from strong winds and blowing sand is a hazard to La Quinta, although the "cove" areas adjacent to the mountains are somewhat protected. Increased development and irrigation in the Coachella Valley has alleviated the hazard of blowing sand somewhat, however many sand sources are still available, including the Whitewater River.

Losses resulting from geologic hazards are generally not covered by insurance policies, causing additional hardship on property owners. The potential for damage can be greatly reduced by:

- Strict adherence to grading ordinances – many of which have been developed as a result of past disasters;
- Sound land planning and project design that avoids severely hazardous areas;
- Detailed, site-specific geotechnical investigations, followed by geotechnical oversight during grading and during construction of foundations and underground infrastructure;
- Effective geotechnical and design review of projects performed by qualified, California-registered engineering geologists, soil engineers, and design engineers; and
- Public education that focuses on reducing losses from geologic hazards, including the importance of proper irrigation and landscaping practices, in addition to the care and maintenance of slopes and drainage devices.

CHAPTER 3: FLOOD HAZARDS

Floods are natural and recurring events that only become hazardous when man encroaches onto floodplains, modifying the landscape and building structures in the areas meant to convey excess water during floods. Unfortunately, floodplains have been alluring to populations for millennia, since they provide level ground and fertile soils suitable for agriculture, as well as access to water supplies and transportation routes. Notwithstanding, these benefits come with a price – flooding is one of the most destructive natural hazards in the world, responsible for more deaths per year than any other geologic hazard. Furthermore, average annual flood losses (in dollars) have increased steadily over the last decades as development in floodplains has expanded.

The city of La Quinta and surrounding areas are, like most of southern California, subject to unpredictable seasonal rainfall. Most years, the winter rains are barely sufficient to turn the hills and mountains green for a few weeks, but every few years the region is subjected to periods of intense and sustained precipitation that results in flooding. Historic flood events that occurred in southern California have resulted in an increased awareness of the potential for public and private losses as a result of this hazard, particularly in the highly urbanized parts of floodplains and alluvial fans. As the population grows, there is an increased pressure to build on flood-prone areas, and in areas upstream of previously developed land. With increased development also comes an increase in impervious surfaces, such as asphalt. Water that used to be absorbed into the ground becomes runoff to downstream areas. If drainage channels that convey storm waters are not designed or improved to carry these increased flows, areas that have not flooded in the past may be subject to flooding in the future. This is especially true for developments near the base of the mountains and downstream from canyons that have the potential to convey mudflows.

3.1 Storm Flooding

3.1.1 Hydrologic Setting

The city of La Quinta and its Sphere of Influence are located at the western edge of the Salton Trough (also known as the Salton Sink), an arid low-lying region with hot summers, cool winters, and infrequent, but potentially violent rainstorms. Most of the existing development in La Quinta is spread across the valley floor – a broad, gently sloping basin formed by a combination of alluvial fans emerging from deeply incised canyons in the adjacent Santa Rosa Mountains, past flooding of the basin's main watercourse, the Whitewater River, and sediments deposited in prehistoric lakes that once occupied the area. The western part of the city encompasses the base of the Santa Rosa Mountains – undeveloped rugged terrain that is part of the Santa Rosa and San Jacinto Mountains National Monument.

La Quinta has no perennial rivers and streams. When a storm arrives, normally dry rocky canyons and riverbeds can quickly become dangerous torrents of water, sand, mud, and rocks, capable of transporting boulders, trees, and even cars. The Whitewater River, with a watershed of more than 1,000 square miles, is the most significant watercourse in the Coachella Valley. Collecting runoff from the San Bernardino, Little San Bernardino, San Jacinto, and Santa Rosa Mountains, the river emerges from the mountains near the southern entrance to the San Gorgonio Pass, and meanders southeastward, eventually reaching the Salton Sea. Like much of its course through the valley, the reach within the city of La Quinta is confined to a man-made channel. Drainage channels in the mountains are deeply incised, however they loose their definition when they reach the valley floor, where sediment-laden water typically spreads out into braided ephemeral stream channels and sheet flow (Figure 3-1). Numerous drainages from the adjacent Santa Rosa Mountains flow toward La Quinta; the most significant of these in terms of flood hazard are Bear Creek and Devil Canyon. La Quinta has numerous facilities in place that have greatly reduced the potential for flooding in the city from these and other sources.

Figure 3-1: Alluvial Fan Outwash from the Rugged Santa Rosa Mountains near La Quinta

3.1.2 Weather and Climate

Southern California owes its agreeable climate of generally mild winters and warm, dry summers to a semi-permanent high-pressure area located over the eastern Pacific Ocean, which deflects storms to the north. During the winter months, this high breaks down, allowing the jet stream to move storms along a more southerly track.

In spite of southern California's reputation for a mild Mediterranean climate, there are varied and distinct climatic zones in close proximity that are controlled by terrain and altitude. The local mountain ranges, including the San Bernardino, San Jacinto, and Santa Rosa Mountains, have a powerful effect on the climatic conditions in this region. Capturing precipitation from strong Pacific storms that pass through, the mountains separate the semi-arid environment to the west from the dry, desert regions to the east. Most precipitation occurs in the winter months, between November and April. However, high-intensity, short-duration tropical thunderstorms emanating from the south are common during the summer and fall, typically occurring July through September. Often accompanied by strong winds, these powerful storms frequently result in localized damage to roadways, power poles, trees, and structures. These storms are highly localized, drenching one area with several inches of rain in a short period of time, while leaving nearby areas completely dry.

The mountains receive significantly more precipitation than the adjacent lowlands. Consequently, mountain thunderstorms can inundate the adjacent valleys with floodwaters, mud, and debris, even if no rain actually falls on the valley. The average yearly precipitation in the La Quinta area is a little more than 3 inches (see Table 3-1), whereas more than 25 inches (average) of precipitation fall annually in the San Jacinto Mountains (Table 3-2).

Table 3-1: Average Annual Rainfall* by Month for the La Quinta Area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Inches	0.6	0.5	0.3	0.1	0.1	0.0	0.1	0.3	0.3	0.2	0.3	0.5	**3.3**

Source: Global Historical Climatology Network
Data based on 1314 months between 1877 and 1989
Weather Station location: Indio, California, about 33.70° N and 116.30° W
Weather Station elevation: About 9 feet above mean sea level
Source: http://www.worldclimate.com/
*Average rainfall = Mean monthly precipitation, including rain, snow, hail, etc.

Table 3-2: Average Annual Rainfall* by Month for the San Jacinto Mountains

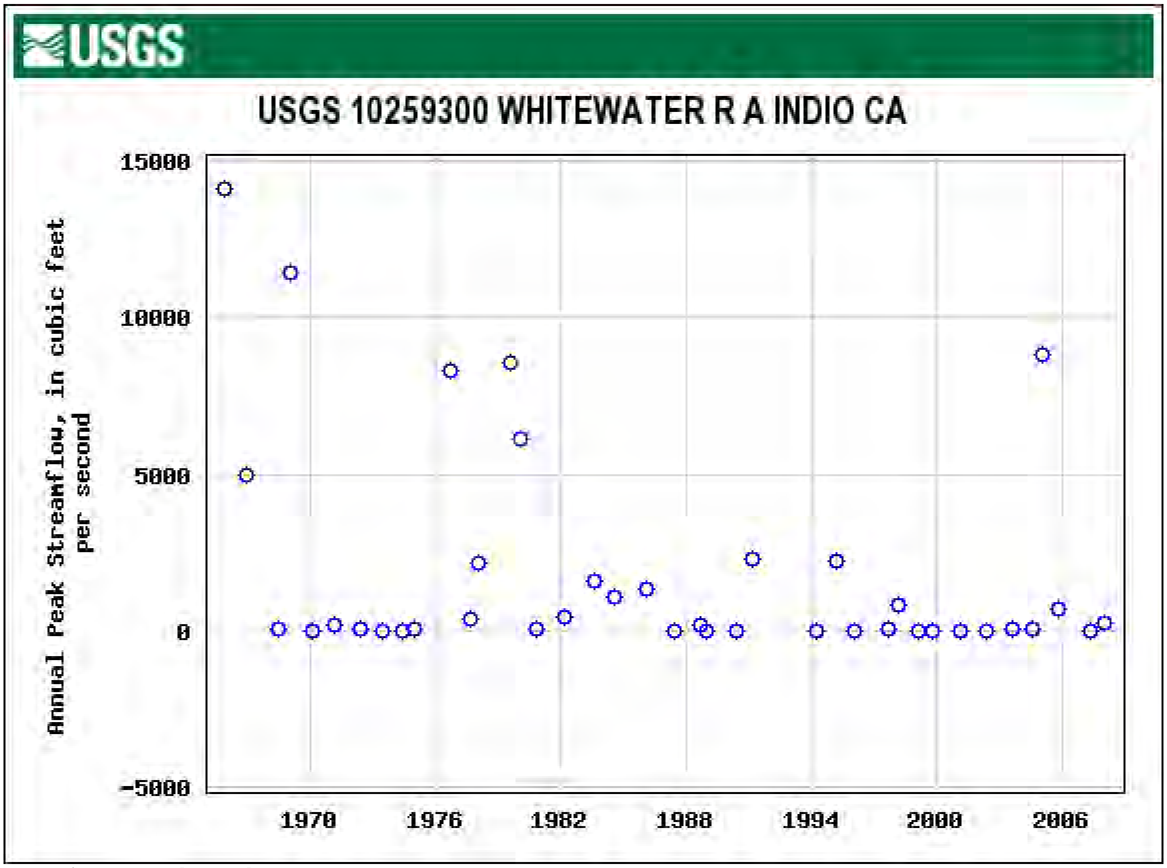
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Inches	6.0	4.7	3.9	1.5	0.3	0.0	0.5	1.2	0.8	0.6	3.3	2.7	**25.3**

Source: NCDC Cooperative Stations
Data based on 8 complete years between 1965 and 1978
Weather Station location: Mount San Jacinto, California, about 33.80°N and 116.63°W
Weather Station elevation: About 8,425 feet above mean sea level
Source: http://www.worldclimate.com/
*Average rainfall = Mean monthly precipitation, including rain, snow, hail, etc.

Not only does rainfall in southern California vary from one location to the next, often within short distances, it is also extremely variable from year to year, with periods of drought alternating with periods of flooding. For instance, annual rainfall totals are illustrated in the peak streamflow graph for a gage on the Whitewater River (see Figure 3-2). This gage is located at the Southern Pacific Railroad Crossing in Indio and therefore best represents the extreme fluctuations in stream discharge for the last 42 years that can occur near La Quinta. With peaks typically at or near zero cubic feet per second (cfs) for most years, peak flows reached more than 10,000 cfs on November 22, 1965 and on January 25, 1969. These floodwaters have been computed to move at high velocities, with the potential to do considerable damage.

Both winter and monsoon storms can impact the La Quinta area, as described further below, in the following paragraphs.

Figure 3-2: Peak Annual Streamflow Values for Gage Station USGS 10259300 located on the Whitewater River near La Quinta



Data for 1966 through 2008
Drainage basin size: 1,073 square miles

Winter Storms. Winter storms are characterized by heavy and sometimes prolonged precipitation over a large area. These storms usually occur between November and April, and are responsible for most of the precipitation recorded in southern California. This is illustrated by the data presented above in Tables 3-1 and 3-2. The storms originate over the Pacific Ocean and move eastward. Mountain ranges, such as the San Bernardino and San Jacinto Mountains, form a rain shadow, slowing down or stopping the eastward movement of this moisture. A significant portion of the moisture is dropped on the mountains as snow. If large storms are coupled with snowmelt from the local mountains, large peak discharges can be expected in the main watersheds at the base of the mountains.

Some of the severe winter storm seasons that have historically impacted the southern California area have been related to El Niño events. El Niño is the name given to a phenomenon that originates every few years, typically in December or early January, in the southern Pacific, off the western coast of South America, but whose impacts are felt worldwide. Briefly, warmer than usual waters in the southern Pacific are statistically linked with increased rainfall in both the southeastern and southwestern United States, droughts in Australia, western Africa and Indonesia, reduced number of hurricanes in the

Atlantic Ocean, and increased number of hurricanes in the Eastern Pacific. Two of the largest and most intense El Niño events on record occurred during the 1982-83 and 1997-98 water years. [A water year is the 12-month period from October 1 through September 30 of the second year. Often a water year is identified only by the calendar year in which it ends, rather than by giving the two years, as above.] These are also two of the worst storm seasons reported in southern California in recent decades.

More recently, the severe storms of December 2004 and January 2005 have been blamed on a different climatic condition, one where the sub-tropical jet stream carries moisture-laden air directly from the tropics to the west coast of California. Because it passes over the Hawaiian Islands, it is commonly referred to as the "Pineapple Express." In December 2004, as this condition was developing, the northern jet stream shifted towards the California coast allowing storms from the north to tap into the deep tropical moisture, dramatically increasing the rainfall in southern California (NOAA, 2005a). Powerful winter storms during February 2005, however, have been attributed to a weak but persistent El Niño condition, combined with an atmospheric condition that blocked or slowed the normal eastward movement of the storms (NOAA, 2005b). These events combined to give the region record-breaking rainfall in the 2005 water year, in addition to spawning numerous waterspouts and small tornadoes.

Monsoon Storms. Typically developing in late summer to fall, these storms are usually most prevalent in the higher mountains and the deserts, but can also move into nearby valleys. They develop when moist, unstable air moves into our area from Mexico through Arizona (Mexican monsoons), from the Sea of Cortez (Gulf Surge), or at times from tropical storms or hurricanes off of Baja California. Once the monsoonal moisture enters California and flows up steep mountain slopes, explosive thunderstorms can develop. Although these high-intensity, short-duration storms typically impact relatively small areas, they often release torrential rainfall that causes flash flooding and mudslides. Frequently packing lightning, hail, very strong wind gusts, and even small tornadoes, thunderstorms cause power outages and damage to people and property. Such storms have impacted La Quinta and the surrounding area in the past.

3.1.3 Past Flooding

Because of the arid climate and the generally dry local washes, residents might be surprised to learn that desert alluvial fans and valleys are the sites of infrequent but catastrophic flooding. Flood hazards to the La Quinta area can be classified into two general categories: 1) flash flooding down natural or man-made channels, and 2) sheet flooding across the valley floor.

Flash floods are short in duration, but have high peak volumes and high velocities. This type of flooding occurs in response to the local geology and geography, and the built environment (man-made structures). The local mountains are steep and consist of rock types that are fairly impervious to water. Consequently, little precipitation infiltrates the ground. When a major storm moves in, water collects rapidly and runs off quickly, making a steep, rapid descent from the mountains into natural or modified channels within the developed valley areas. Because of the steep terrain and the constant shedding of debris from the mountain slopes (primarily as dry ravel and rock falls), flood flows often carry large amounts of mud, sand, and rock fragments. Sheet flow occurs when the capacities of the existing channels (either natural or man-made) are exceeded or when channels become blocked by debris or structures, causing water to flow into adjacent areas.

Using historical records dating back to 1769, the Army Corp of Engineers determined that there were relatively large flood events in the Whitewater River basin in 1825, 1833, 1840, 1850, 1859, 1862, 1867, 1876, 1884, 1886, and 1891. Damaging floods also occurred in January 1916, December 1921, April 1926, February 1927, February 1937, March 1938, and December 1940. More recently, substantial floods occurred in November 1965, December 1966, January 1969, February 1969, and September 1976. The maximum flood of record in the lower Coachella Valley occurred in 1965. In general, the most extensive flood damage occurs on alluvial fans between the base of the mountains and the Whitewater River – the areas where most development in the valley has taken place (FEMA, 2008a).

3.1.4 National Flood Insurance Program (NFIP)

Because floods are the leading cause of natural disaster losses in the United States, the nation invests significant resources to reduce the risk of flooding. Floods can be widespread and cause catastrophic losses, therefore insurance companies generally consider flood hazards too costly to insure (National Research Council, 2009). In order to manage the increasing flood losses, the Federal Emergency Management Agency (FEMA) was mandated by the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 to evaluate flood hazards and provide affordable flood insurance to residents in communities that regulate future floodplain development. To that end, FEMA created **Flood Insurance Rate Maps (FIRMS)** for the purpose of setting flood insurance premiums and for regulating the elevations and flood proofing of structures in mapped flood zones.

The NFIP is required to offer federally subsidized flood insurance to property owners in those communities that adopt and enforce floodplain management ordinances that meet minimum criteria established by FEMA. Floodplain management may include such measures as requirements for zoning, subdivisions, and building construction, as well as special-purpose floodplain ordinances. The National Flood Insurance Reform Act of 1994 further strengthened the NFIP by providing a grant program for State and community flood mitigation projects. The act also established the **Community Rating System (CRS)**, a system for crediting communities that implement measures to protect the natural and beneficial functions of their floodplains, and managing their erosion hazard.

The City of La Quinta has participated as a regular member in the NFIP since 1985 (Community ID No. 060709#). The City's most current effective FIRM maps are dated 2008 (12 community panels), however maps and flood elevations are amended periodically to reflect future changes. For unincorporated areas, the County of Riverside has participated as a regular member in the NFIP since 1980 (Community ID No. 060245#).

Because La Quinta and Riverside County are participating members of the NFIP, flood insurance is available to any property owner in the General Plan area. In fact, to secure financing to buy, build, or improve structures in a Special Flood Hazard Zone (SFHZ – see definition below), property owners are required to purchase flood insurance. Lending institutions that are federally regulated or federally insured must determine if the structure is located in a SFHZ and must provide written notice requiring flood insurance.

FEMA recommends that most property owners, whether residential or commercial, purchase and keep flood insurance, even if they are not located in a mapped flood hazard zone. Keep in mind that approximately 20% to 25% of all flood claims occur outside of mapped high flood risk areas, and typical homeowner or business insurance policies do not cover flooding. Residents or business owners that rent property can also purchase coverage for the contents of their homes or business inventories. In low to moderate risk areas, property owners should ask their insurance agents if they are eligible for the FEMA Preferred Risk Policy, which provides inexpensive flood insurance protection. Insured property owners can be reimbursed for all covered losses, even if the flood-impacted zone is not officially declared a Federal disaster area. Residents should also be aware that localized flooding could be caused by a temporary situation, such as a storm drain inlet or culvert that becomes blocked by debris during a storm. Hillside areas are generally outside of mapped flood zones, however these areas can be vulnerable to mudslides, which are also covered under flood insurance.

FEMA also recommends that residents do not forgo purchasing insurance, assuming instead Federal disaster assistance will pay for flood damage. In order to receive assistance, a community must first be declared a Federal disaster area, and these declarations are issued in less than 50% of flood events. Remember also that Federal assistance is usually in the form of a loan, which must be repaid with interest. Furthermore, if uninsured property owners do receive Federal assistance, they must purchase flood insurance to remain eligible for future disaster relief.

3.1.5 FEMA Flood Zone Mapping

Flood risk information presented on FIRMs is based on historic, meteorological, hydrologic, and hydraulic data, as well as topographic surveys, open-space conditions, flood-control works, and existing development. Rainfall-runoff and hydraulic models are utilized by the FIRM program to analyze flood potential, adequacy of flood protective measures, surface-water and groundwater interchange characteristics, and the variable efficiency of mobile (sand bed) flood channels. For riverine flooding, the extent of potential flooding is predicted from statistical analyses and hydrologic models that rely heavily on data from U.S. Geological Survey stream gages and land surface topography.

Some FEMA flood map features that are relevant to the residents of the General Plan area are:

Flood Insurance Study (FIS). To prepare FIRMs that illustrate the extent of flood hazards in a flood-prone community, FEMA conducts engineering studies referred to as Flood Insurance Studies. The La Quinta General Plan area is included in the FIS for Riverside County; the most recent version is dated August 2008. This document includes community descriptions, flooding sources (including the Whitewater River and Bear Creek), information of historical flooding, existing flood protection measures, hydrologic and hydraulic analyses, and definition of potential flood areas.

Special Flood Hazard Area (SFHA). Using information gathered in FIS studies, FEMA engineers and cartographers delineate Special Flood Hazard Areas on FIRMs. SFHAs are those areas subject to a high risk of inundation by a "base flood" which FEMA sets as a 100-year flood. As mentioned above, SFHAs are regulated zones, requiring the mandatory purchase of flood insurance. They are also subject to special standards and regulations that apply to new construction, and in some cases, existing buildings. Floodplain regulations required by the NFIP apply only to properties located in a SHFA. However, these are minimum requirements, and local jurisdictions may regulate areas outside of the SHFAs, based on knowledge specific to their area.

Base Flood. The base flood, also called the **100-year flood,** is defined by looking at the long-term average period between floods of a certain size, and identifying the size of a flood that has a 1% chance of occurring during any given year. This base flood has a 26% chance of occurring during a 30-year period, the length of most home mortgages. However, a recurrence interval such as "100 years" represents only the long-term average period between floods of a specific magnitude; rare floods can in fact occur at much shorter intervals or even within the same year.

The base flood is a regulatory standard used by the National Flood Insurance Program (NFIP) as the basis for insurance requirements nationwide. The Flood Disaster Protection Act requires owners of all structures in identified SFHAs to purchase and maintain flood insurance as a condition of receiving Federal or federally related financial assistance, such as mortgage loans from federally insured lending institutions.

The base flood is also used by Federal agencies, as well as most County and State agencies, to administer floodplain management programs. The goals of floodplain management are to reduce losses caused by floods, while preserving and restoring the natural and beneficial value of the floodplain.

Base flood elevation (BFE). This is the calculated elevation of the water surface during a base flood event. The BFE is important because it is the regulatory standard used for the elevation or flood proofing of structures. Further, the height of the first floor elevation above the BFE determines the amount of the flood insurance premium. BFEs are shown on FIRMs for those flooding sources that have been analyzed using detailed methods. BFEs on the maps have been rounded to whole-foot elevations and are intended for use in flood insurance rating purposes only. For construction or floodplain management, data in the FIS should be utilized as well.

Floodway. The basis of floodplain management is the concept of the "floodway." FEMA defines this as the channel of a river or other watercourse, and the adjacent land areas that must be kept free of encroachment in order to discharge the base flood without cumulatively increasing the water surface elevation more than a certain height. The intention is not to preclude development, but to assist communities in managing sound development in areas of potential flooding. The community is responsible for prohibiting encroachments into the floodway unless it is demonstrated by detailed hydrologic and hydraulic analyses that the proposed development will not increase the flood levels downstream.

Mapped flood areas outside of the 100-year flood zone. FIRMs in the La Quinta area also show the estimated limits of areas with moderate to low risk of flooding. The flood having a 0.2% annual chance of occurring (also called the 500-year flood) is usually the basis for these categories, with moderate risk defined as the zone between the limits of the 100-year and 500-year floods, and low risk defined as the area outside of the 500-year flood limits. These zones may also include areas where the base flood is less than one foot deep, or where the drainage basin is small (less than one square mile), or areas that are protected from the base flood by levees. Flood insurance is available for properties in these zones, but is not mandated by the NFIP.

Letter of Map Revision (LOMR). A Letter of Map Revision is a modification to the FIRM or floodway boundaries, generally based on physical changes that affect the hydraulic or hydrologic characteristics of the flood source (usually as a result of development or new flood control facilities). The letter is typically accompanied by an annotated copy of the portion of the map that has been revised. Modifications to the FIRM maps are usually made in response to an agency supplying new hydraulic data that show that the flooding hazard in a specific area has changed or has been abated. Two LOMRs have been issued for the La Quinta area since the FIRMs were updated in 2008 (FEMA, 2009a,b). The flood zones shown on Plate 3-1 include the modifications brought about by these two LOMRs.

In addition to their original purpose of setting insurance rates and regulating flood hazards, FIRMs are now widely used by local and regional planners for other purposes, including land-use planning, emergency preparedness and response, natural resource management, and risk assessment. However, it should be noted there are many uncertainties inherent in the establishment of FEMA flood zones (Larsen, 2009). Given the importance of these maps, some of the limitations that communities should be aware of are discussed below:

- It is important to realize that FIRMs only identify potential flood areas based on the conditions at the time of the study, and do not consider the impacts of future changes in the area. Conditions that affect the maps and decisions made on their basis may include changes in corporate boundaries, changes in population, man-made and natural changes to the landscape, removal of vegetation, changes to hydrologic systems, construction of flood control facilities, and potential climate changes. These changes in the environment may increase or reduce the area susceptible to flooding.
- The level of detail studied and presented on the maps, as well as the boundaries of the area studied, depend on the type of flood hazard, the funding available, and the risk of flood damage at the time of the analysis. For instance, areas studied by approximate methods do not provide BFEs on the map, and some study areas are limited in extent.
- The maps do not necessarily identify all areas of flooding. For instance, drainages of small size, areas of localized ponding during storms, or areas where drainages are restricted by temporary or permanent structures may not be shown.
- The analytical process relies on many assumptions and incomplete data. Data used to construct the maps may be too old, incomplete, interpolated, and/or

inaccurate. For instance, in relatively flat floodplains, small elevation errors in the topography can result in large errors in flood zone boundaries.

- One major drawback is the very short time period for which we have meteorological records. Research on some parts of southern California has shown slight climate fluctuations between wet and dry cycles have occurred since the late 1800s (Hereford and Longpre, 2009). Future global climate change is still intensely debated, but many scientists now believe even slight global warming could bring an increase in precipitation overall, although the specific effects on the La Quinta region are not known.
- Long-term changes in the watershed or floodplain, primarily from man's encroachment, are even harder to predict. Even flood-control structures, such as berms and levees, can increase the flood risk to other areas. The design of high-density developments often requires taking drainages that used to be spread over a wide area and constricting them into narrow channels, thereby increasing the velocity and erosive power of the flow, and perhaps leading to overtopping. Consequently, there are clearly limitations in using hydrologic calculations based on past, imperfect records to predict the future.
- Larsen (2009) also argues that the process of placing a line on a map (flood zone boundaries) conveys a sense of certainty about the risk to the public and policy makers that does not exist.

Flood Map Modernization Program. Because many flood maps and related products were outdated, FEMA started its Map Modernization Program in 2003 to reduce reliance on paper maps and transition to digital processes for distributing and reading flood maps. The program also includes collecting new flood data for unmapped areas. Based on funding limitations and feedback from stakeholders, FEMA changed its goals mid way through the program. Rather than try to create digitized flood maps for the entire nation, it was decided to improve the accuracy of the newly updated maps by establishing two criteria: 1) a floodway boundary standard that would insure flood maps match the topographic data used (although use of the standard itself does not validate the accuracy of the topographic data); and 2) guidelines for determining whether an existing flood study is adequate for current use or if an updated study is needed. The adjusted goal is to have 65% of the continental U.S. land area and 92% of the population covered by digital maps (National Research Council, 2009).

Risk MAP Program. With the Risk Map Program approved in March 2009, FEMA is moving from simply portraying flood hazard zones on maps to more accurately communicating and assessing risk to the local community. Building on the digitized maps, FEMA has developed a five-year plan to fill in data gaps, increase public awareness, increase their outreach on flood risks, support state and local agencies in risk-based mitigation planning, and provide an enhanced digital platform that improves communication and sharing of risk data.

3.1.6 Flood Zone Mapping in La Quinta

As part of the National Flood Insurance Program, the extent of flooding on portions of the La Quinta General Plan area have been analyzed through the Flood Insurance Study for Riverside County (2008). The potential flood zones mapped by FEMA are published in

Flood Insurance Rate Maps, which were updated in 2008. Since that time however, through mapping and detailed analyses, two floodplain map revisions within the city were approved by FEMA (FEMA, 2009a,b). According to the Master Drainage Plan (MDP) for the City of La Quinta, the result of this effort is that all developed areas within city limits are now outside of the 100-year flood zone and are removed from the requirement to purchase flood insurance (Psomas, 2009). Those areas shown as Zone A (susceptible to the 100-year flood) are now primarily restricted to flood control channels, detention or retention basins, and some golf course locations that double as flood retention areas.

FEMA studies indicate several parts of La Quinta and its Sphere of Influence could still be flooded during an event stronger than the 100-year storm (shown as shaded Zone X). However it should be noted that within portions of the General Plan limits, some study areas are limited and the flood zones are incomplete. Consequently, there are areas outside of the mapped flood zones that are likely to be subject to flood hazards. The current FEMA flood zones for the General Plan area, including modifications by the recent LOMRs, are illustrated on Plate 3-1.

3.1.7 Existing Flood Protection Measures

According the La Quinta Master Drainage Plan, flood control facilities fall into two categories:

- Regional facilities that convey runoff from the mountains to the Whitewater River. The river and its major tributary facilities are maintained by the Coachella Valley Water District.
- Local facilities that collect runoff from local streets and properties, and direct it to the regional channels and basins. These are usually maintained by the City.

The La Quinta Master Drainage Plan is a document prepared by the Costa Mesa office of PSOMAS in March 2009. The Master Drainage Plan includes several figures, in Atlas Map format, that show the existing storm drain facilities in the city. The study included an analyis the existing public facilities with emphasis on those FEMA flood zones in the northeastern portion of the Cove that were the focus of the Letters of Map Revision (LOMRs) discussed in Section 3.1.5; percolation testing to verify or establish infiltration rate criteria for future retention basins; identification of hydraulic deficiencies, if any, in the existing storm drain infrastructure; determination of potential improvements to the storm drain infrastructure; and prioritization and cost estimation of recommended projects. The document, which did not require adoption by City Council, is available on the City's website at http://www.la-quinta.org/Index.aspx?page=590. The Master Drainage Plan was originally used to document the changes to the floodway boundaries that allowed the City to procure, in January 2009, two Letters of Map Revision (LORMs). The Plan is now used primarily for maintenance purposes, as it shows the locations of the existing storm drains and catch basins in the city (Brian Ching, City of La Quinta Public Works Department, personal communication, September 1, 2009).

Flood control facilities in the La Quinta area are briefly described below and major structures are identified on Plate 3-1.

Whitewater River: The Whitewater River is the principal drainage course through the city of La Quinta. It is typically dry, but flows southeasterly through the Coachella Valley when carrying water. Much of the Whitewater River, including the portion that transects La Quinta, is a man-made channel that somewhat follows the recent historical path of the natural river. The channel is known throughout the valley as the Coachella Valley Stormwater Channel (in some publications it is referred to as the Whitewater River Storm Channel). The 50±-mile long channel is mostly unlined with an average cross-section width of about 260 feet.

Levees constructed of large sandpiles with no reinforcement occur along portions of the channel. The levees are easily eroded and require periodic maintenance. Although the levees conform to FEMA standards for 100-year flood protection, the instability of the sand limits the dependability of that protection (FEMA, 2008a). According to the most recent (August 2008) FIRMs, the levees along the Whitewater River that impact La Quinta are Provisionally Accredited by FEMA, meaning that the owner of the levee (the Coachella Valley Water District) was to provide documentation to FEMA showing that the levees comply with Federal regulations regarding their 100-year flood protection capabilities (per Title 44, Chapter 1 of the Code of Federal Regulations, Section 65.10) by August, 2009. According to Mr. Tesfaye Demissie, Associate Stormwater Engineer with the Coachella Valley Water District (CVWD), the CVWD submitted the appropriate documentation to FEMA by the due date, but, as of September 2, 2010, the levees have not yet been certified by FEMA. FEMA points out that because these structures are potentially at risk of overtopping or failure, citizens, community officials, builders, insurance agents, lenders, and others need to understand the risk to life and property that resides behind these levees. This is a risk that even the best flood control system cannot completely eliminate. Communities traversed by these flood-protection facilities are well served by having evacuation plans in place, and property owners adjacent to these structures are encouraged to purchase flood insurance.

FEMA (2008a) indicates there is a potential for a major breakout of the Whitewater River during a 100-year storm at the bend in the river between Jefferson Street and Miles Avenue, where the man-made channel deviates from the natural watercourse. FEMA attributes this to the lack of sufficient channel capacity at that point and the erodibility of the levee at the bend. A breakout would result in a 50% loss of channel capacity and send floodwaters throughout the cities of Indio and Coachella, as well as the northeast corner of the La Quinta's Sphere of Influence. FEMA also reports that improvements to levees along the Coachella Valley and La Quinta Evacuation Storm Channels have improved this situation.

Bear Creek System: The Upper Bear Creek System consists of the Upper Bear Creek Training Dike, the Upper Bear Creek Detention Basin, Bear Creek, and Bear Creek Channel. The Upper Bear Creek Training Dike diverts into Bear Creek the 100-year stormwater runoff, occurring mostly in the form of sheetflow, from 1.7 square miles of drainage area to the south of the dike (FEMA, 1991). Runoff collected in Bear Creek then flows into the Upper Bear Creek Detention Basin. Riprap slope protection is provided to prevent erosion of the dike embankment. Flows from Bear Creek enter the basin via a 5:1 (horizontal:vertical) sloped inlet protected by one-quarter to one-ton riprap. The Upper Bear Creek Detention Basin has a storage capacity of 752 acre-feet for temporary detention of storm runoff and debris. Outflows from the basin enter the Bear Creek Channel via a rectangular concrete spillway in the basin embankment. After a storm, the water detained in the basin drains into the Bear Creek Channel until the basin is empty.

The 2.5-mile long Bear Creek Channel is designed to convey floodwaters from the Upper Bear Creek Detention Basin and to intercept runoff from the mountains to the west. It is a soil-cement lined, trapezoidal channel that is 40 feet in width, except for the last 400 feet, which is 70 feet wide. Channel bank heights were designed so that the channel can carry the 100-year event. Four side inlet channels along the western margin of the Bear Creek Channel drain smaller canyons and carry flows into the channel while storing debris during a major storm event. In its upper two miles, the channel has a relatively steep gradient of 2.8%, whereas in its lower 0.5 miles, it has a gradient of 0.15% and contains a drop structure just upstream of the Oleander Reservoir. The levee on the east side of Bear Creek Channel is also at this time provisionally accredited, and like the levees along the Whitewater River, has not yet been certified by FEMA, although the appropriate documentation was provided by the CVWD.

Oleander Reservoir: This reservoir is a detention basin within an existing golf course, namely the La Quinta Resort and Club Mountain Course. The reservoir collects storm runoff from the Bear Creek system as well as the drainage areas north and west of the reservoir, and discharges it into the La Quinta Evacuation Channel. During a 100-year storm the water level in the reservoir is projected to rise to an elevation of 44 feet.

La Quinta Resort Channel: This man-made channel intercepts runoff from drainages in the mountains west of the La Quinta Resort area, and carries it to the Oleander Reservoir for detention. According to the CVWD, this channel is not part of their flood control system. At this time it is unclear whether the City of La Quinta or the La Quinta Resort is responsible for the maintenance of this structure.

East La Quinta System: The East La Quinta System consists of the East La Quinta Channel and several detention basins. The system is designed to collect runoff from the hills east and southeast of Calle Bermudas. The channel intercepts flows from drainages in the hills and carries it, along with outflows from the Calle Tecate Detention Basin, to the Avenue Bermudas Detention Basin. The East La Quinta Channel is trapezoidal with full riprap lining that follows the existing natural drainage channel. The Avenida Bermudas Detention Basin is designed to handle runoff and retain debris from the surrounding drainage areas. During a 100-year flood the system discharges flows through a 60-inch reinforced concrete buried storm drain to the La Quinta Evacuation Channel.

La Quinta Evacuation Channel: The La Quinta Evacuation Channel is about 3.5 miles long, extending from the Bear Creek Channel to the Coachella Valley Stormwater Channel. Winding through developed areas in the valley, its main purpose is to collect and convey stormwater from the various flood control systems throughout La Quinta. The channel consists of two distinct reaches: the lower 2.4-mile reach is a 50-foot wide trapezoidal earthen channel, while the upper 1.1 miles is an irregularly shaped grass-lined channel.

NOTES:

This map is intended for general land use planning only. Information on this map is not sufficient to serve as a substitute for detailed geologic investigations of individual sites, nor does it satisfy the evaluation requirements set forth in geologic hazard regulations.

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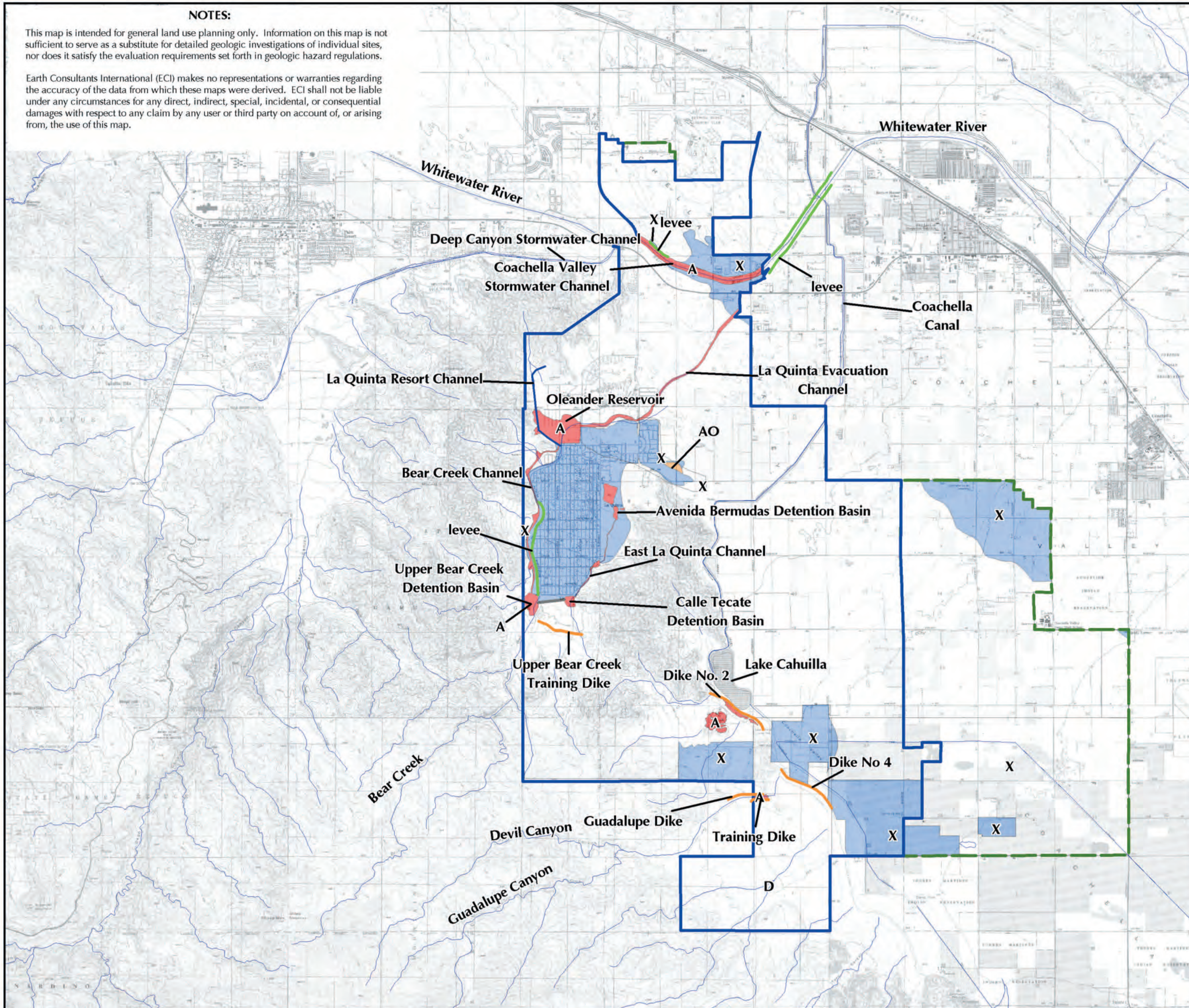

FEMA Flood Zones and Flood Control Facilities La Quinta, California

Explanation

High Risk Areas

A — Zone that corresponds to the 100-year flood areas, as determined by approximate methods. Because detailed hydraulic analyses were not performed, no base flood elevations or depths are shown. Mandatory flood insurance is required.

AO — Zone that corresponds to 100-year shallow flood areas where average depths are between 1 and 3 feet (usually from sheet flow on sloping terrain).* Mandatory flood insurance is required.

Moderate and Low Risk Areas

X — Zone that corresponds to areas of 500-year flood; areas of 100-year flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 100-year flood. No base flood elevations or depths are shown. Flood insurance is available but not required.

X — Zone that corresponds to areas outside of the 500-year flood. No base flood elevations or depths are shown. Flood insurance is available but not required.

Undetermined Risk Areas

D — Zone that corresponds to unstudied areas where flood hazards are undetermined, but flooding is possible. Flood insurance is available but not required.

Dike

Levee

River or stream

La Quinta City Boundary

La Quinta Sphere of Influence

* For elevations or depths see original FEMA Flood Insurance Rate Maps available at the City, County, or www.fema.gov.

N W E S

Scale: 1:84,000

7000 0 7000

Feet

2 0 2

Kilometers

Base Map: USGS Topographic Map from Sure!MAPS RASTER, 1997
Source: Federal Emergency Management Agency, San Bernardino, Flood Insurance Rate Map (Panel Numbers: 06065C2229G, 06065C2241G, 06065C2243G, 06065C2231G, 06065C2232G, 06065C2233G, 06065C2234G, 06065C2237G, 06065C2239G, 06065C2244G, 06065C2261G, 06065C2900G)

Earth Consultants International

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Date: 2010

Plate 3-1

Dikes: In addition to the Bear Creek Training Dike mentioned above, there are several other dikes near the base of the mountains that provide protection to properties on the distal parts of alluvial fans. The Bureau of Reclamation constructed the District's Eastside Dike to protect the Coachella Canal. Two other dikes, Dike No. 2 and Dike No. 4, totaling 5.2 miles, were constructed on the west side of the valley to protect Lake Cahuilla and lands between Avenue 58 and Avenue 66. (Guadalupe Dike and Guadalupe Training Dike are considered part of Dike No. 4). Funds were obtained under a loan approved by voters in the canal-irrigated area. Dike No. 4 has been certified by FEMA, but Dike No. 2 has not (T. Demissie, Coachella Valley Water District, personal communication, September 2, 2009).

Local Structures: These include storm drains, culverts, and catch basins located both within private developments and along local streets. These small retention and catch basins, located throughout the city, serve to collect stormwater and irrigation runoff, where it is temporarily retained during a storm, or where it is detained and allowed to evaporate or percolate into the ground. The locations of these retention and catch basins are shown on the Map Book Atlas pages that are part of the City's Master Drainage Plan (PSOMAS, 2009; available from the City's website at http://www.la-quinta.org/Index.aspx?page=590. Unless waived by the City Engineer, all new developments are required to retain on site the stormwater runoff produced over the peak twenty-four hour period of a one-hundred year storm (Municipal Code Title 13, §13.24.120).

3.1.8 Future Flood Protection

La Quinta's Master Drainage Plan indicates no substantial drainage deficiencies exist within the city, and therefore, no major capital improvements are needed (PSOMAS, 2009). However the report notes there are areas within the city where local flooding could occur, primarily due to the lack of local retention basins and storm drains that locally are undersized.

As new developments are considered, it is important that hydrologic studies be conducted to assess the impact that increased development may have on the existing development down gradient. These studies should quantify the effects of increased runoff and alterations to natural stream courses. Such constraints should be identified and analyzed in the earliest stages of planning. If any deficiencies are identified, the project proponent needs to prove that these can be mitigated to a satisfactory level prior to proceeding forward with the project, in accordance with California Environmental Quality Act (CEQA) guidelines. Mitigation measures typically include flood-control devices such as catch basins, storm drain pipelines, culverts, detention basins, desilting basins, velocity reducers, as well as debris basins for protection from mud and debris flows below hillside areas. Flood control requirements for new subdivisions in the City of La Quinta are spelled out in the City's Municipal Code, Title 13, §13.24.120.

The methodology for analysis and design of flood-control structures is set forth by the Riverside County Flood Control and Water Conservation District (RCFC&WCD). Developers of new projects are required to design flood control measures and submit them for review. Future responsibilities for operation of regional flood control facilities will be with the Coachella Valley Water District (CVWD), whereas the local storm drains and other structures outside of the regional system are the responsibility of the City of La

Quinta. Therefore, both agencies must be involved in the planning and approval of mitigation measures, to assure compatibility.

Across the United States, substantial changes in the philosophy, methodology and mitigation of flood hazards are currently in the works. For example:

- Some researchers have questioned whether or not the current methodology for evaluating average flood recurrence intervals is still valid, since we are presently experiencing a different, warmer and wetter climate. Even small changes in climate can cause large changes in flood magnitude (Gosnold et al., 2000).
- Flood control in undeveloped areas should not occur at the expense of environmental degradation. Certain aspects of flooding are beneficial and are an important component of the natural processes that affect regions far from the particular area of interest. For instance, lining major channels with concrete reduces the area of recharge to the underlying groundwater table. Thus there is a move to leave nature in charge of flood control. The advantages include lower cost, preservation of wildlife habitats and improved recreation potential.
- Floodway management design in land development projects can also include areas where stream courses are left natural or as developed open space, such as parks or golf courses. Where flood control structures are unavoidable, they are often designed with a softer appearance that blends in with the surrounding environment.
- Environmental legislation is increasingly coming in conflict with flood control programs. Under the authority of the Federal Clean Water Act and the Federal Endangered Species Act, development and maintenance of flood control facilities has been complicated by the regulatory activities of several Federal agencies including the U.S. Army Corps of Engineers, the Environmental Protection Agency, and the U.S. Fish and Wildlife Service. For instance, FEMA requires that the County and its incorporated cities maintain the carrying capacity of all flood control facilities and floodways. However, this requirement can conflict with mandates from the U.S. Fish and Wildlife Service regarding maintaining the habitat of endangered or threatened species. Furthermore, the permitting process required by the Federal agencies is lengthy, and can last several months to years. Yet, if the floodways are not cleared of vegetation and other obstructing debris in a timely manner, future flooding of adjacent areas could develop.

As the population of La Quinta grows, the consequences of flooding are likely to increase. In light of the uncertainties with respect to estimating floods, land use planning in the City and the General Plan area in general could benefit from additional mapping in undeveloped areas, a conservative approach to permitting, and a strong adherence to an area-wide, long-term vision for flood safety as individual projects are considered.

3.1.9 Flood Protection Measures for Property Owners

As discussed above, flooding remains a risk locally, especially in areas of future development where adequate mapping of the flood hazard is incomplete. Mitigation measures that can reduce the flood hazard are discussed below.

At the community level:

- Continue the enforcement of the County's provisions for flood hazard reduction, tract drainage, and storm water management (Ordinance Nos. 458, 460, and 754) and the City's flood hazard and floodplain regulations (Municipal Code Chapters 8.11, 8.70, 9.140 and 13.24.120, available from http://qcode.us/codes/laquinta/). These regulations include construction standards that address the major causes of flood damage – i.e., structures that are not adequately elevated, flood-proofed, or otherwise protected from flooding. The regulations apply to new construction or substantial improvements, and include provisions for anchoring, placement of utilities, elevating the lowest floors, flood resistant materials, and other methods to minimize damage.
- FEMA recommends that communities be proactive in protecting lives and preventing property damage in areas with provisional structures (such as levees and dikes), due to the risk of overtopping of failure of the structure. This might include having evacuation plans in place and encouraging residents and businesses to buy flood insurance.
- Encourage residents to purchase flood insurance for areas outside of the 100-year flood zone.
- Develop methods to conduct real-time storm warnings and evacuations if necessary.
- Continue to educate the public on the risks of flooding, including the uncertainties inherent in flood hazard zoning.
- Establish easements for entrenched flow paths.
- Create flood overlays for zoning and land use maps.
- Create an atmosphere of working with nature and the natural processes inherent to the semi-arid environment characteristic of this area.

For Property Owners:

- Elevate new homes on pads, foundations, or piers in flood-prone areas.
- Orient new homes and pads to provide minimum obstruction to the direction of flow, and do not force flows onto adjacent properties.
- Try to accommodate natural flows rather than restricting them.
- Any grading to direct flow around a home or structure should include directing it back to its natural path downstream.
- Protect foundations or piers from erosion and scour.
- Numerous methods are available for flood protection – which methods are most appropriate for an individual lot should be based on the local conditions surrounding and upstream from the lot.
- Some lots may require special engineering studies to determine the extent of the hazard and to design appropriate mitigation.

FEMA has identified several flood protection measures that can be implemented by property owners to reduce flood damage. These include: installing waterproof veneers on the exterior walls of buildings; putting seals on all openings, including doors, to prevent the entry of water; raising electrical components above the anticipated water level; and installing backflow valves that prevent sewage from backing up into the house through the drainpipes. Obviously, these changes vary in complexity and cost, and some need to be carried out only by a professional licensed contractor. For additional information and ideas, refer to the FEMA web page at www.fema.gov. Structural modifications require a permit from the City or County Building Departments. Refer to them for advice regarding whether or not flood protection measures would be appropriate for your property.

3.1.10 Bridge Scour

Nationwide, several catastrophic collapses of highway and railroad bridges due to scouring and a subsequent loss of support of foundations have occurred. This has led to a nationwide inventory and evaluation of bridges (Richardson and others, 1993). Scour at highway bridges involves sediment-transport and erosion processes that cause streambed material to be removed from the bridge vicinity. Scour is generally separated into components of pier scour, abutment scour, and contraction scour. Pier scour occurs when flow impinges against the upstream side of the pier, forcing the flow in a downward direction and causing scour of the streambed adjacent to the pier. Abutment scour happens when flow impinges against the abutment, causing the flow to change direction and mix with adjacent main-channel flow, resulting in scouring forces near the abutment toe. Contraction scour occurs when flood flow is forced back through a narrower opening at the bridge, where an increase in velocity can produce scour. Total scour for a particular site is the combined effects of each component. While different materials scour at different rates, the ultimate scour attained for different materials is similar and depends mainly on the duration of peak streamflow acting on the material (Lagasse and others, 1991). Scour can occur within the main channel, on the floodplain, or both. California's seismic retrofit program of bridges includes underpinning of foundations that is expected to help reduce the vulnerability to undermining of the foundations by scour.

For the La Quinta Evacuation Channel, the Eisenhower Drive and Washington Street crossings are considered "all-weather flood channel crossings." Washington Street and Jefferson Boulevard are the city's main crossing of the Whitewater River. Both of these are also "all-weather flood channel crossings," consisting of bridges over the river. The limits of the floodway areas shown in Plate 3-1, however, are based on the assumption that there are no obstructions, such as debris, in the floodway. Obstructions in the floodway can result in higher and wider zones of flooding than those shown, with the potential to impact the bridge crossings. It is thus very important that these crossings continue to be inspected by City's Public Works Department during and after flooding, for obstructions and potential scour damage, respectively.

Roads that extend across the branch of the All-American Canal in La Quinta include Jefferson Street and Avenues 50 and 52. Given that the canal is not a flood-protection facility and its water level is not impacted by precipitation or runoff, flooding of the roads that extend across the canal is not likely.

3.2 Seismically Induced Inundation

3.2 1 Dam Failure

Seismically induced inundation refers to flooding that results when water retention structures, such as dams, fail due to an earthquake. Statutes governing dam safety are defined in Division 3 of the California State Water Code (California Department of Water

Resources, 1986). These statutes empower the California Division of Dam Safety to monitor the structural safety of dams that are greater than 25 feet in height or have more than 50 acre-feet of storage capacity.

A review of records maintained by the California Office of Emergency Services indicates that there are no existing dams with the potential to inundate the city of La Quinta. Lake Cahuilla, although a water storage facility with more than the 50-acre feet of storage capacity does not fall under the purview of the Division of Dam Safety because it is not impounded by an artificial barrier (dam). Lake Cahuilla is the terminal reservoir on the Coachella Branch of the All-American Canal, was constructed in 1969 to serve as storage for a reserve supply of irrigation water needed chiefly in emergency periods when water is used to combat weather conditions. Since it takes water 24 hours to arrive in the Coachella Valley after being ordered from Imperial Dam, the lake gives the district some latitude when weather conditions change unexpectedly.

Constructed at a cost of $1.56 million, exclusive of rights-of-way and land acquisitions, the lake was financed by a rehabilitation and betterment loan from the U.S. Bureau of Reclamation approved by voters in the Colorado River service area. Located between Avenues 56 and 58, west of Jefferson Street, against the foothills of the Santa Rosa Mountains on the west side of the Coachella Valley (Plate 3-1), the lake is three-quarters of a mile long and half that wide at its widest point. The lake is between 11 and 12 feet deep and contains approximately 1,500 acre-feet of water. At the time of its construction it was the largest soil-cement lined reservoir in the world. The basin of the lake was excavated to provide soil for building dikes 25 feet high and 100 feet wide. The bottom of the lake was sealed with six inches of compacted soil cement. The Riverside County Parks Department has an agreement with the water district for development of the lake and surrounding grounds for general recreational use by the public on a fee basis.

The modern Lake Cahuilla is not to be confused with the Ancient Lake Cahuilla, a natural lake that covered a large portion of the Salton Trough more than anout 400 years ago (see Section 2.1 and Plate 2-1).

Local flooding associated with failure of the Coachella Canal levees or overtopping of Lake Cahuilla (such as a result of seiching) has not been evaluated. The levee systems could be impacted by a severe earthquake, with the potential for the foundation soils to fail as a result of lateral spreading (see Chapter 1, Section 1.6). Should these systems fail catastrophically, development immediately downstream could be impacted; however, no engineering analyses that include potential inundation mapping are currently available for these structures. Liquefaction and lateral spreading damaged Imperial Valley canals during earthquakes in 1979 and 1987, and more recently, as a result of the Easter Sunday (Sierra El Mayor-Cucapah) earthquake of 2010. However, field reconnaissance of the Imperial Valley canal following the 2010 earthquake showed that, although there was significant slumping and lateral spreading along the canals, none of them failed, and there were no reports of flooding as a result of slumping of the canal levees. The Coachella Valley Water District considers it unlikely for the branch of the All-American Canal that extends across La Quinta to fail during an earthquake. The only place where flooding could occur is where the canal extends across the SilverRock Resort. In this area, and according to the CVWD, the City of La Quinta removed the canal's 3.5-foot overboard, and as a result, overtopping as a result of surges in the water level in the canal has occurred a few times.

When this has happened, the overflow water has gone into the golf course, with no ill effects to the residential structures in the area (M. Schaefer, Coachella Valley Water District, personal communication, September 2, 2009).

3.2.2 Inundation From Above-Ground Storage Tanks

Seismically induced inundation can also occur if strong ground shaking causes structural damage to above-ground water tanks. If a tank is not adequately braced and baffled, sloshing water can lift a water tank off its foundation, splitting the shell, damaging the roof, and bulging the bottom of the tank (causing what is referred to as "elephant's foot") (EERI, 1992). Movement can also shear off the pipes leading to the tank, releasing water through the broken connections. These types of damage were reported as a result of the 1992 Landers, 1992 Big Bear, 1994 Northridge, and 2010 Sierra El Mayor-Cucapah (Baja California) earthquakes. The Northridge earthquake alone rendered about 40 steel tanks non-functional (EERI, 1995), including a tank in the Santa Clarita area that failed and inundated several houses below. As a result of lessons learned from the 1992 and 1994 earthquakes, revised standards for design of steel water tanks were adopted in 1994 (Lund, 1994). The revised tank design includes flexible joints at the inlet/outlet connections to accommodate movement in any direction.

According to the Coachella Valley Water District, there are ten water reservoirs in La Quinta. They are all constructed of welded steel and are built to current seismic standards as well as current standards of the American Water Works Association. The reservoirs are summarized below.

Table 3-3: Above-ground Water Tanks in La Quinta

Reservoir No.	Location	Year Built	Capacity (millions of gallons)
6630-1	550' southeast of Ave. Villa and Ave. Bermudas	1986	5.0
6630-2	550' southeast of Ave. Villa and Ave. Bermudas	2004	10.0
6631-1	¼ mile south of Calle Tecate on service road	1986	1.0
6631-2	¼ mile south of Calle Tecate on service road	1995	4.0
6632-1	1 mile south of Calle Tecate on service road	1987	0.25
6632-2	1 mile south of Calle Tecate on service road	1995	1.5
6723	PGA West on Southern Hills	1982	0.5
6725	½ mile northwest of Lake Cahuilla on service road	2000	9.8
6726	¾ mile northwest of Lake Cahuilla on service road	2008	12.0
6730	Schwabaker Road at The Quarry	1995	0.5

Source: Coachella Valley Water District.

Water lost from tanks during an earthquake can affect not only structures down slope from the tanks, but can significantly reduce the water resources available to suppress earthquake-induced fires. Damaged tanks and water mains can also limit the amount of water available to residents. The main aqueducts that deliver imported water to many parts of southern California are likely to suffer extensive damage if a major earthquake occurs on either the San Andreas fault or other nearby active faults. Repairs to these aqueducts could take weeks to months (Toppozada et al., 1993; Jones et al., 2008); as discussed in Chapter 1, Section 1.9, in the La Quinta area, the potable water system is expected to be non-functional for at least 30 days, if not longer, following a M7.8 earthquake on the San Andreas fault. Similar damage can be expected to the groundwater wells in the region, also limiting the water available to the community after an earthquake. Therefore, it is of paramount importance that the water storage tanks in the area retain their structural integrity during an earthquake, so water demands after an earthquake can be met. In addition to evaluating and retrofitting water reservoirs to meet current standards, this also requires that the tanks be kept at or near full capacity at all times.

3.3 Summary

The City of La Quinta and the Coachella Valley Water District, the agency in charge of flood control, have been proactive is protecting developed areas of the city from significant flooding. Currently there are no developed areas (except for some golf courses that double as stormwater retention areas) in the city that are within a FEMA Special Flood Hazard Zone requiring property owners to purchase flood insurance. There are however, areas within the city subject to localized flooding, due most commonly to the lack of adequately sized storm drains or lack of temporary retention facilities. Unpredictable local flooding can also occur during storms if catch basins or inlets get clogged with debris, or if levees become damaged or overtopped. Further, there are significant developed areas in the city that are zoned by FEMA as having a moderate flood hazard, meaning they may be flooded during a storm stronger than the 100-year event, or subject to shallow flooding during a 100-year storm. For these reasons FEMA encourages property owners outside of the Special Flood Hazard Areas to purchase flood insurance.

In undeveloped areas of the city and in its Sphere of Influence, there are significant areas mapped by FEMA as having a moderate flood hazard, but more importantly, planners, builders, and property owners should be aware that flood zone mapping in these areas is incomplete and not well defined.

The City should have evacuation plans in place in the event of a levee or dike failure. This is especially important for critical facilities such as schools. This also true for facilities using, storing, or otherwise involved with substantial quantities of onsite hazardous materials, unless all requirements for elevation, anchoring, and flood proofing have been satisfied. Hazardous materials should always be stored in watertight containers that are not capable of floating.

Because La Quinta is located in a seismically active region, inundation resulting from failure of a water retention or storage facility during a strong earthquake is a concern. There are no State-regulated dams within or upstream of the city that could lead to inundation. However many of the levees are constructed of sand and built on sand, leaving them vulnerable to seismic settlement or possibly liquefaction if a strong earthquake occurred during or after a stormy period. Lake Cahuilla, the local canals, and other open bodies of water in the city are subject to seiches (sloshing of water back and forth) during an earthquake, which in itself can damage containment structures such as levees and berms.

According to the Coachella Valley Water District, the water storage tanks in the area are built to current seismic standards. Given the anticipated extensive damage to the regional potable water system (including aqueducts, water mains, and distribution lines) resulting from a large-magnitude earthquake on the San Andreas fault, it is very important that the water storage tanks in the area remain structurally sound, and that they be maintained as full of water as possible. Thus, even if the water distribution pipelines are damaged, the City would have access to stored water that can be distributed to the community using water trucks or other similar methods until the pipelines are repaired.

The City should continue to require that future planning for new developments consider the impact on flooding potential, as well as the impact of flood control structures on the environment, both locally and regionally. Flood control should not be introduced in the undeveloped areas at the expense of environmental degradation. Land development planning should continue to consider leaving watercourses natural wherever possible, or continuing to develop them as parks, nature trails, golf courses or other types of recreation areas that can withstand inundation.

APPENDIX A: REFERENCES and USEFUL WEBSITES

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Useful Websites

Geologic Hazards in General

http://geohazards.cr.usgs.gov/

USGS Hazard Team website. Hazard information on commonly recognized hazards such as earthquakes, landslides, and volcanoes. Contains maps and slide shows.

http://www.usgs.gov/themes/hazard.html

A webpage by the USGS on hazards such as hurricanes, floods, wildland fire, wildlife disease, coastal storms and tsunamis, and earthquakes. Also has information on their Hazard Reduction Program.

http://www.consrv.ca.gov/cgs/index.htm

Homepage for the California Geologic Survey (formerly the Division of Mines and Geology). Information their publications (geologic reports and maps), programs (seismic hazard mapping, Alquist-Priolo Earthquake Fault Study Zone maps); and other brochures (asbestos, natural hazard disclosure).

www.oes.ca.gov/

California Governor's Office of Emergency Services website. Contains information on response plans regarding natural disasters (earthquakes), terrorist attacks, and electrical outages, and information on past emergencies.

Geologic Maps

http://wrgis.wr.usgs.gov/wgmt/scamp/scamp.html

Homepage for the Southern California Aerial Mapping Project (SCAMP), which is the USGS' program to update geologic maps of Southern California at a 1:100,000 scale and release these in a digital GIS format.

Seismic Hazards, Faults, and Earthquakes

http://gmw.consrv.ca.gov/shmp/

Shows the current list of seismic hazard maps available from the California Geologic Survey. These can be downloaded in a pdf format.

www.scecdc.scec.org.

Southern California Earthquake data center (hosted by SCEC, USGS, and Caltech. Shows maps and data for recent earthquakes in Southern California and worldwide. Catalogs of historic earthquakes.

http://www.consrv.ca.gov/cgs/rghm/quakes/index.htm

List of California earthquakes (date, magnitude, latitude longitude, description of damage).

http://geohazards.cr.usgs.gov/eq/html/canvmap.html
Website at the USGS Earthquake Hazard's Program that lists seismic acceleration maps available for downloading.

www.seismic.ca.gov/
Homepage of the California Seismic Safety Commission. Contains information on California earthquake legislation, safety plans, and programs designed to reduce the hazards from earthquakes. Includes several publications of interest, including "The Homeowner's Guide to Earthquake Safety." Also contains a catalog of recent California earthquakes.

http://neic.usgs.gov/
Homepage of the National Earthquake Information Center. Maintains an extensive global seismic database on earthquake parameters. Its mission is to rapidly determine the location and size of all destructive earthquakes worldwide, and disseminate that information as quickly as possible to concerned national and international agencies, scientists, and the public in general.

http://www.scsn.org/
Site where Shakemaps for actual and scenario earthquakes can be obtained.

Landslides and Debris Flows

http://landslides.usgs.gov/index.html
USGS Landslide webpage. Links to their publications, recent landslide events, and bibliographic databases.

http://gmw.consrv.ca.gov/shmp/
California Geologic Survey website on Seismic Hazard maps.

http://vulcan.wr.usgs.gov/Glossary/Lahars/framework.html
USGS Volcanic Observatory website list of links regarding mudflows, debris flows and lahars.

http://www.fema.gov/hazards/landslides/landslif.shtm
Federal Emergency Management Agency (FEMA) fact sheet website about landslides and mudflows.

Flooding, Dam Inundation, and Erosion (Note: the information on some of these web sites has been removed due to safety concerns; but may be posted again in the future in limited form).

http://vulcan.wr.usgs.gov/Glossary/Sediment/framework.html
US Geological Survey Volcanic Observatory website list of links regarding sediment and erosion.

http://www.usace.army.mil/public.html#Regulatory
US Army Corps of Engineers website regarding waterway regulations.

http://www.fema.gov/fima/

FEMA website about the National Flood Insurance Program.

http://www.worldclimate.com/
Precipitation rates at different rain stations in the world measured over time.

http://waterdata.usgs.gov
Stream gage measurements for rivers throughout the US.

Others

http:// www.bsc.ca.gov
Site of the California Building Standards Commission. Provides information regarding the status of the building codes being considered for future approval in California.

APPENDIX B: GLOSSARY

Acceleration – The rate of change for a body's magnitude, direction, or both over a given period of time.

Active fault – For implementation of Alquist-Priolo Earthquake Fault Zoning Act (APEFZA) requirements, an active fault is one that shows evidence of having experienced surface displacement within the last 11,000 years. APEFZA classification is designed for land use management of surface rupture hazards. A more general definition by the National Academy of Sciences (1988) is "a fault that on the basis of historical, seismological, or geological evidence has the finite probability of producing an earthquake." The American Geological Institute (1972) defines an active fault as one along which there is recurrent movement, usually indicated by small, periodic displacements or seismic activity.

Adjacent grade – Elevation of the natural or graded ground surface, or structural fill, abutting the walls of a building. See *highest adjacent grade* and *lowest adjacent grade*.

Aeolian (or eolian) – Related to or pertaining to the wind; carried, eroded or deposited by wind action.

Aftershocks – Minor earthquakes following a greater one and originating at or near the same location.

Aggradation – The building up of earth's surface by deposition of sediment.

Alluvial – Pertaining to, or composed, of alluvium, or deposited by a stream or running water.

Alluvial fan – A low, outspread relatively flat to gently sloping surface consisting of loose sediment that is shaped like an open fan, deposited by a stream at the place where the stream comes out of a narrow canyon onto a broad valley or plain. Alluvial fans are steepest near the mouth of the canyon, and spread out, gradually decreasing in gradient, away from the stream source.

Alluvium – Surficial sediments of poorly consolidated gravels, sand, silts, and clays deposited by flowing water.

Amplitude – The height of a wave between its crest (high point) and its mid-point.

Anchor – To secure a structure to its footings or foundation wall in such a way that a continuous load transfer path is created and so that it will not be displaced by flood, wind, or seismic forces.

Aplite – A light-colored igneous rock with a fine-grained texture and free from dark minerals. Aplite forms at great depths beneath the earth's crust.

Aquifer – A body of rock or sediment that contains sufficient saturated permeable material to allow the flow of ground water and to yield economically significant quantities of ground water to wells and springs.

Argillic – Alteration in which certain minerals of a rock or sediments are converted to clay. Also said of a soil horizon characterized by the illuvial accumulation of clay.

Armor – To protect slopes from *erosion* and *scour* by *flood* waters. Techniques of armoring include the use of riprap, gabions, or concrete.

Artesian – An adjective referring to ground water confined under hydrostatic pressure. The water level in wells drilled into an **artesian** aquifer (also called a confined aquifer) will stand at some height above the top of the aquifer. If the water reaches the ground surface, the well is referred to as a "flowing" **artesian** well.

Aspect – The direction a slope faces.

Attenuation – The reduction in amplitude of a wave with time or distance traveled.

A zone – Under the *National Flood Insurance Program*, area subject to inundation by the *100-year flood* where wave action does not occur or where waves are less than 3 feet high, designated Zone A, AE, A1-A30, A0, AH, or AR on a *Flood Insurance Rate Map* (FIRM).

Base flood – *Flood* that has as 1-percent probability of being equaled or exceeded in any given year. Also known as the *100-year flood*.

Base Flood Elevation (BFE) – Elevation of the *base flood* in relation to a specified datum, such as the *National Geodetic Vertical Datum* or the *North American Vertical Datum*. The Base Flood Elevation is the basis of the insurance and *floodplain management* requirements of the *National Flood Insurance Program*.

Basement – Under the *National Flood Insurance Program*, any area of a building having its floor subgrade on all sides. (Note: What is typically referred to as a "walkout basement," which has a floor that is at or above grade on at least one side, is not considered a basement under the *National Flood Insurance Program*.)

Bedding – The arrangement of a sedimentary rock or deposit in beds or layers of varying thickness and character.

Bedrock – Designates hard rock that is in its natural intact position and underlies soil or other unconsolidated surficial material.

Bench – A grading term that refers to a relatively level step excavated into earth material on which fill is to be placed. A bench is also a long, narrow, relatively level or gently inclined platform of land or rock bounded by steeper slopes above and below.

Biotite – A general term to designate all ferromagnesian micas. More specifically, biotite is a widely distributed and important rock-forming mineral that is usually black, brown or dark green, and that is an original constituent of igneous and metamorphic rocks, or a detrital constituent of sedimentary rocks.

Blind thrust fault – A thrust fault is a low-angle reverse fault (where the top block is being or has been pushed over the bottom block). A "blind" thrust fault refers to one that does not reach the surface.

Braided stream – A stream that divides into or follows an interlacing or tangled network of several, small, branching and reuniting shallow channels separated from each other by channel bars. Also referred to as an **anastomosing** stream.

Brush – A collective term that refers to stands of vegetation dominated by shrubby, woody plants, or low-growing trees.

Building code – Regulations adopted by local governments that establish standards for construction, modification, and repair of buildings and other structures.

Cast-in-place concrete – Concrete that is poured and formed at the construction site.

CEQA – The California Environmental Quality Act (Chapters 1 through 6 of Division 13 of the Public Resources Code). A state statute that requires state and local agencies to identify the significant environmental impacts of their actions and to avoid or mitigate those impacts, if feasible.

Cladding – Exterior surface of the building envelope that is directly loaded by the wind.

Clay – A rock or mineral fragment having a diameter less than 1/256 mm (4 microns, or 0.00016 in.). A clay commonly applied to any soft, adhesive, fine-grained deposit.

Climate – The average condition of weather over time in a given region.

Code official – Officer or other designated authority charged with the administration and enforcement of the code, or a duly authorized representative, such as a building, zoning, planning, or *floodplain management* official.

Collapse – A relatively sudden change in the volume of a soil mass resulting in the local settlement of the ground surface, with the potential to cause significant damage to overlying structures. If due to strong ground shaking, the soil grains in the soil column are re-arranged by the shaking so that the pore space between grains is reduced and the grains become more tightly packed, resulting in the overall reduction of the thickness of the soil column. This is referred to as earthquake-induced subsidence. Collapse can also occur in certain types of sediments, where with the introduction of water (due to an increase in irrigation, for example), the cement between soil grains dissolves, allowing the soil particles to become more tightly packed, again resulting in the local settlement of the ground surface. This process is also referred to as **hydro-collapse** or **hydroconsolidation**.

Column foundation – Foundation consisting of vertical support members with a height-to-least-lateral-dimension ratio greater than three. Columns are set in holes and backfilled with compacted material. They are usually made of concrete or masonry and often must be braced. Columns are sometimes known as posts, particularly if the column is made of wood.

Compressible soil – Geologically young unconsolidated sediment of low density that may compress under the weight of a proposed fill embankment or structure.

Concrete Masonry Unit (CMU) – Building unit or block larger than 12 inches by 4 inches by 4 inches made of cement and suitable aggregates.

Conglomerate – A coarse-grained sedimentary rock composed of rounded to subangular fragments larger than 2 mm in diameter set in a fine-grained matrix of sand or silt, and commonly cemented by calcium carbonate, iron oxide, silica or hardened clay. The consolidated equivalent of gravel.

Connector – Mechanical device for securing two or more pieces, parts, or members together, including anchors, wall ties, and fasteners.

Consolidation – Any process whereby loosely aggregated, soft earth materials become firm and cohesive rock. Also the gradual reduction in volume and increase in density of a soil mass in response to increased load or effective compressive stress, such as the squeezing of fluids from pore spaces.

Corrosion-resistant metal – Any nonferrous metal or any metal having an unbroken surfacing of nonferrous metal, or steel with not less than 10 percent chromium or with not less than 0.20 percent copper.

Coseismic rupture - Ground rupture occurring during an earthquake but not necessarily on the causative fault.

Cretaceous – The final period of the Mesozoic era (before the Tertiary period of the Cenozoic era), thought to have occurred between about 136 and 65 million years ago.

Dead load – Weight of all materials of construction incorporated into the building, including but not limited to walls, floors, roofs, ceilings, stairways, built-in partitions, finishes, cladding, and other similarly incorporated architectural and structural items and fixed service equipment.

Debris – (Seismic) The scattered remains of something broken or destroyed; ruins; rubble; fragments. (Flooding, Coastal) Solid objects or masses carried by or floating on the surface of moving water.

Debris impact loads – Loads imposed on a structure by the impact of flood-borne debris. These loads are often sudden and large. Though difficult to predict, debris impact loads must be considered when structures are designed and constructed.

Debris flow – A saturated, rapidly moving saturated earth flow with 50 percent rock fragments coarser than 2 mm in size which can occur on natural and graded slopes.

Debris line – Line left on a structure or on the ground by the deposition of debris. A debris line often indicates the height or inland extent reached by *flood* waters.

Deflected canyons – A relatively spontaneous diversion in the trend of a stream or canyon caused by any number of processes, including folding and faulting.

Deformation - A general term for the process of folding, faulting, shearing, compression, or extension of rocks.

Design flood – The greater of either (1) the *base flood* or (2) the *flood* associated with the *flood hazard area* depicted on a community's flood hazard map, or otherwise legally designated.

Design Flood Elevation (DFE) – Elevation of the *design flood*, or the flood protection elevation required by a community, including wave effects, relative to the *National Geodetic Vertical Datum*, *North American Vertical Datum*, or other datum.

Development – Under the *National Flood Insurance Program*, any manmade change to improved or unimproved real estate, including but not limited to buildings or other structures, mining, dredging, filling, grading, paving, excavation, or drilling operations or storage of equipment or materials.

Differential settlement – Non-uniform settlement; the uneven lowering of different parts of an engineered structure, often resulting in damage to the structure. Sometimes included with liquefaction as ground failure phenomenon.

Dike – A tabular shaped, igneous intrusion that cuts across bedding of the surrounding rock.

Diorite – A group of igneous rocks that form at great depth beneath the earth's crust. These rocks are intermediate in composition between acidic and basic rocks.

Displacement - The length, measured in kilometers (km), of the total movement that has occurred along a fault over as long a time as the geologic record reveals.

DMA 2000 - Disaster Mitigation Act of 2000. Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended by Public Law 106-390, October 30, 2000. DMA 2000 is intended to establish a continuing means of assistance by the Federal Government to State and local governments in carrying out their responsibilities to alleviate the suffering and damage which result from disasters by (1) revising and broadening the scope of existing disaster relief programs; (2) encouraging the development of comprehensive disaster preparedness and assistance plans, programs, capabilities, and organizations by the States and by local governments; (3) achieving greater coordination and responsiveness of disaster preparedness and relief programs; (4) encouraging individuals, States, and local governments to protect themselves by obtaining insurance coverage to supplement or replace governmental assistance; (5) encouraging hazard mitigation measures to reduce losses from disasters, including development of land use and construction regulations; and (6) providing Federal assistance programs for both public and private losses sustained in disasters .

Dynamic analysis – A complex earthquake-resistant engineering design technique capable of modeling the entire frequency spectra, or composition, of ground motion. The method is used to evaluate the stability of a site or structure by considering the motion from any source or mass, such as that dynamic motion produced by machinery or a seismic event.

Earth flow – Imperceptibly slow-moving surficial material in which 80% or more of the fragments are smaller than 2 mm, including a range of rock and mineral fragments.

Earthquake – Vibratory motion propagating within the Earth or along its surface caused by the abrupt release of strain from elastically deformed rock by displacement along a fault.

Earth's crust – The outermost layer or shell of the Earth.

Effective Flood Insurance Rate Map (FIRM) – See *Flood Insurance Rate Map*.

El Niño – Phenomenon that originates, every few years, typically in December or early January, in the southern Pacific Ocean, off of the western coast of South America, characterized by warmer than usual water. This warmer water is statistically linked with increased rainfall in both the southeastern and southwestern United States, droughts in Australia, western Africa and Indonesia, reduced number of earthquakes in the Atlantic Ocean, and increased number of hurricanes in the Eastern Pacific.

Encroachment – Any physical object placed in a floodplain that hinders the passage of water or otherwise affects the flood flows.

Engineering geologist – A geologist who is certified by the State as qualified to apply geologic data, principles, and interpretation to naturally occurring earth materials so that geologic factors affecting planning, design, construction, and maintenance of civil engineering works are properly recognized and used. An engineering geologist is particularly needed to conduct investigations, often with geotechnical engineers, of sites with potential ground failure hazards.

Environmental Protection Agency (EPA) – Federal agency tasked with ensuring the protection of the environment and the nation's citizens.

Ephemeral stream – A stream or reach of a stream that flows only briefly in direct response to precipitation.

Epicenter – The point at the Earth's surface directly above where an earthquake originated.

Erodible soil – Soil subject to wearing away and movement due to the effects of wind, water, or other geological processes during a flood or storm or over a period of years.

Erosion – Under the *National Flood Insurance Program*, the process of the gradual wearing away of landmasses. In general, erosion involves the detachment and movement of soil and rock fragments, during a flood or storm or over a period of years, through the action of wind, water, or other geologic processes.

Erosion analysis – Analysis of the short- and long-term *erosion* potential of soil or strata, including the effects of wind action, *flooding* or *storm surge*, moving water, wave action, and the interaction of water and structural components.

Evacuation – Movement of people from an area, typically their homes, to another area considered to be safe, typically in response to a natural or man-made disaster that makes an area unsafe for people.

Expansive soil – A soil that contains clay minerals that take in water and expand. If a soil contains sufficient amount of these clay minerals, the volume of the soil can change significantly with changes in moisture, with resultant structural damage to structures founded on these materials.

Fanglomerate – A sedimentary rock consisting of a heterogeneous mix of fragments of all sizes, originally deposited in an alluvial fan and subsequently cemented into a firm rock. Generally said of the coarser, consolidated rock material that occurs in the upper part of an alluvial fan.

Fault – A fracture (rupture) or a zone of fractures along which there has been displacement of adjacent earth material.

Fault segment – A continuous portion of a fault zone that is likely to rupture along its entire length during an earthquake.

Fault slip rate – The average long-term movement of a fault (measured in cm/year or mm/year) as determined from geologic evidence.

Federal Emergency Management Agency (FEMA) – Independent agency created in 1979 to provide a single point of accountability for all Federal activities related to disaster mitigation and emergency preparedness, response and recovery. FEMA administers the *National Flood Insurance Program*.

Federal Insurance Administration (FIA) – The component of the *Federal Emergency Management Agency* directly responsible for administering the flood insurance aspects of the *National Flood Insurance Program*.

Feldspar – The most widespread of any mineral group; constitutes ~60% of the earth's crust. Feldspars occur as components of all kinds of rocks and, on decomposition, yield a large part of the clay of a soil.

Fill – Material such as soil, gravel, or crushed stone placed in an area to increase ground elevations or change soil properties.

Five-hundred (500)-year flood – *Flood* that has as 0.2% probability of being equaled or exceeded in any given year.

Flash flood – A local and sudden flood or torrent overflowing a stream channel in an usually dry valley, carrying an immense load of mud and rock fragments, and generally resulting from a rare and brief but heavy rainfall over a relatively small area having steep slopes.

Flood – A rising body of water, as in a stream or lake, which overtops its natural and artificial confines and covers land not normally under water. Under the *National Flood Insurance Program*, either:

(a) a general and temporary condition or partial or complete inundation of normally dry land areas from:

(1) the overflow of inland or tidal waters,

(2) the unusual and rapid accumulation or runoff of surface waters from any source, or

(3) mudslides (i.e., mudflows) which are proximately caused by flooding as defined in (2) and are akin to a river of liquid and flowing mud on the surfaces of normally dry land areas, as when the earth is carried by a current of water and deposited along the path of the current, or

(b) the collapse or subsidence of land along the shore of a lake or other body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels or suddenly caused by an unusually high water level in a natural body of water, accompanied by a severe storm, or by an unanticipated force of nature, such as flash flood or abnormal tidal surge, or by some similarly unusual and unforeseeable event which results in flooding as defined in (1), above.

Flood-damage-resistant material – Any construction material capable of withstanding direct and prolonged contact (i.e., at least 72 hours) with floodwaters without suffering significant damage (i.e., damage that requires more than cleanup or low-cost cosmetic repair, such as painting).

Flood elevation – Height of the water surface above an established elevation datum such as the *National Geodetic Vertical Datum*, *North American Vertical Datum*, or *mean sea level*.

Flood hazard area – The greater of the following: (1) the area of special flood hazard, as defined under the *National Flood Insurance Program*, or (2) the area designated as a flood hazard area on a community's legally adopted flood hazard map, or otherwise legally designated.

Flood insurance – Insurance coverage provided under the National Flood Insurance Program.

Flood Insurance Rate Map (FIRM) – Under the *National Flood Insurance Program*, an official map of a community, on which the *Federal Emergency Management Agency* has delineated both the special hazard areas and the risk premium zones applicable to the community. (Note: The latest FIRM issued for a community is referred to as the *effective FIRM* for that community.)

Flood Insurance Study (FIS) – Under the *National Flood Insurance Program*, an examination, evaluation, and determination of *flood* hazards and, if appropriate, corresponding *water surface elevations*, or an examination, evaluation, and determination of mudslide (i.e., mudflow) and/or flood-related erosion hazards in a community or communities. (Note: The *National Flood Insurance Program* regulations refer to Flood Insurance Studies as "flood elevation studies.")

Flood-related erosion area or flood-related erosion prone area – A land area adjoining the shore of a lake or other body of water, which due to the composition of the shoreline or bank and high water levels or wind-driven currents, is likely to suffer *flood*-related *erosion* damage.

Flooding – See *Flood*.

Floodplain – Under the *National Flood Insurance Program*, any land area susceptible to being inundated by water from any source. See *Flood*.

Floodplain management – Operation of an overall program of corrective and preventive measures for reducing *flood* damage, including but not limited to emergency preparedness plans, flood control works, and *floodplain management regulations*.

Floodplain management regulations – Under the *National Flood Insurance Program*, zoning ordinances, subdivision regulations, building codes, health regulations, special purpose ordinances (such as floodplain ordinance, grading ordinance, and erosion control ordinance), and other applications of police power. The term describes such state or local regulations, in any combination thereof, which provide standards for the purpose of *flood* damage prevention and reduction.

Floodway – The channel of a river or other watercourse, and the adjacent land areas that must be kept free of encroachment in order to discharge the base flood without cumulatively increasing the water surface elevation more than a certain height.

Flow failure – A type of liquefaction-induced failure that generally occurs in slopes greater than 3 degrees, and that is characterized by the displacement, often over tens to hundreds of feet, of blocks of soil riding on top of the liquefied substrate.

Footing – Enlarged base of a foundation wall, pier, post, or column designed to spread the load of the structure so that it does not exceed the soil bearing capacity.

Footprint – Land area occupied by a structure.

Freeboard – Under the *National Flood Insurance Program*, a factor of safety, usually expressed in feet above a *flood* level, for the purposes of *floodplain management*. Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than the heights calculated for a selected size flood and floodway conditions, such as the hydrological effect of urbanization of the watershed.

Gabbro – A group of dark-colored intrusive igneous rocks composed principally of plagioclase. The approximate intrusive equivalent of basalt.

Geomorphology – The science that treats the general configuration of the Earth's surface. The study of the classification, description, nature, origin and development of landforms, and the history of geologic changes as recorded by these surface features.

Geotechnical engineer – A licensed civil engineer who is also certified by the State as qualified for the investigation and engineering evaluation of earth materials and their interaction with earth retention systems, structural foundations, and other civil engineering works.

Gneiss – A metamorphic rock in which bands of granular minerals alternate with bands in which mineral have a flaky or prismatic habit, with less than 50 percent of the minerals showing preferred parallel orientation.

Grading – Any excavating or filling or combination thereof. Generally refers to the modification of the natural landscape into pads suitable as foundations for structures.

Granite – Broadly applied, any completely crystalline, quartz-bearing, plutonic rock.

Ground failure – Permanent ground displacement produced by fault rupture, differential settlement, liquefaction, or slope failure.

Ground lurching – A form of earthquake-induced ground failure where soft, saturated soils move in a wave-like manner in response to intense seismic ground shaking, forming ridges or cracks at the surface.

Ground oscillations – A type of liquefaction-induced failure where liquefaction occurs at depth, in an area where the ground surface is too level to permit the lateral displacement of the overlying soil blocks. The blocks instead separate from one another and oscillate above the liquefied layer. This may result in the opening and closing of fissures or cracks, and the formation of sand boils or volcanoes.

Ground rupture – Displacement of the earth's surface as a result of fault movement associated with an earthquake.

Hazardous material (HAZMAT) – Substance that has the ability to harm humans, property or the environment. The United States Environmental Protection Agency defines hazardous waste as substances that:

1) may cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness;
2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of or otherwise managed; and
3) whose characteristics can be measured by a standardized test or reasonably detected by generators of solid waste through their knowledge of their waste.

Hazardous waste is also ignitable, corrosive, or reactive (explosive) (EPA 40 CFR 260.10). A material may also be classified as hazardous if it contains defined amounts of toxic chemicals.

Highest adjacent grade – Elevation of the highest natural or regarded ground surface, or structural fill, that abuts the walls of a building.

Holocene – An epoch of the Quaternary period spanning from the end of the Pleistocene to the present time (the past about 11,000 years).

Hornblende – The most common mineral of the amphibole group. It is a primary constituent in many intermediate igneous rocks.

Hydrocompaction – Settlement of loose, granular soils that occurs when the loose, dry structure of the sand grains held together by a clay binder or other cementing agent collapses upon the introduction of water.

Hydrodynamic loads – Loads imposed on an object, such as a building, by water flowing against and around it. Among these loads are positive frontal pressure against the structure, drag effect along the sides, and negative pressure on the downstream side.

Hydrostatic loads – Loads imposed on a surface, such as a wall or floor slab, by a standing mass of water. The water pressure increases with the square of the water depth.

Hypocenter – The earthquake focus, that is, the place at depth, along the fault plane, where an earthquake rupture started.

Igneous – Type of rock or mineral that formed from molten or partially molten magma.

Infiltration – The process by which water seeps into the soil, as influenced by soil texture, soil structure, and vegetation cover.

Intensity – A measure of the effects of an earthquake at a particular place. Intensity depends on the earthquake magnitude, distance from the epicenter, and on the local geology.

Invasive plants – Plants that aggressively expand their ranges over the landscape, typically at the expense of native plants that are displaced or destroyed by the newcomers. Invasive species are typically considered a major threat to biological diversity.

Jet stream – A relatively narrow stream of fast-moving air in the middle and upper troposphere. Surface cyclones develop and move along the jet stream.

Jetting (of piles) – Use of a high-pressure stream of water to embed a pile in sandy soil.

Joist – Any of the parallel structural members of a floor system that support, and are usually immediately beneath, the floor.

ka – thousands of years before present.

Lacustrine flood hazard area – Area subject to inundation by *flooding* from lakes.

Landslide – A general term covering a wide variety of mass-movement landforms and processes involving the downslope transport, under gravitational influence, of soil and rock material en masse.

Lateral force – The force of the horizontal, side-to-side motion on the Earth's surface as measured on a particular mass; either a building or structure.

Lateral spreading – Lateral movements in a fractured mass of rock or soil which result from liquefaction or plastic flow or subjacent materials.

Left-lateral fault – A strike-slip fault across which a viewer would see the block on the opposite side of the fault move to the left.

Lifeline system – Linear conduits or corridors for the delivery of services or movement of people and information (e.g., pipelines, telephones, freeways, railroads)

Lineament – Straight or gently curved, lengthy features of earth’s surface, frequently expressed topographically as depressions or lines of depressions, scarps, benches, or change in vegetation.

Liquefaction – Changing of soils (unconsolidated alluvium) from a solid state to weaker state unable to support structures; where the material behaves similar to a liquid as a consequence of earthquake shaking. The transformation of cohesionless soils from a solid or liquid state as a result of increased pore pressure and reduced effective stress.

Live loads – *Loads* produced by the use and occupancy of the building or other structure. Live loads do not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load, or dead load. See *Loads*.

Load-bearing wall – Wall that supports any vertical load in addition to its own weight.

Loads – Forces or other actions that result from the weight of all building materials, occupants and their possessions, environmental effects, differential movement, and restrained dimensional changes. Permanent loads are those in which variations over time are rare or of small magnitude. All other loads are variable loads.

Lowest floor – Under the *National Flood Insurance Program*, the lowest floor of the lowest enclosed area (including basement) of a structure. An unfinished or *flood*-resistant enclosure, usable solely for parking of vehicles, building access, or storage in an area other than a basement is not considered a building's lowest floor, provided that the enclosure is not built so as to render the structure in violation of *National Flood Insurance Program* regulatory requirements.

Lowest horizontal structural member – In an elevated building, the lowest beam, *joist*, or other horizontal member that supports the building. *Grade beams* installed to support vertical foundation members where they enter the ground are not considered lowest horizontal structural members.

Ma – millions of years before present.

Macroburst – A strong downdraft over 2.5 miles in diameter that can cause damaging winds lasting 5 to 20 minutes. Formed by an area of significantly rain-cooled air that after hitting ground levels spreads out in all directions.

Magnitude – A measure of the size of an earthquake, as determined by measurements from seismograph records. Also refers to both a fire's intensity and severity.

Main shock – The biggest earthquake of a sequence of earthquakes that occur fairly close in time and space. Smaller shocks before the main shock are called **foreshocks**; smaller shocks that occur after the main shock are called **aftershocks**.

Major earthquake – Capable of widespread, heavy damage up to 50+ miles from epicenter; generally near Magnitude range 6.5 to 7.0 or greater, but can be less, depending on rupture mechanism, depth of earthquake, location relative to urban centers, etc.

Manufactured home – Under the *National Flood Insurance Program*, a *structure*, transportable in one or more sections, which is built on a permanent chassis and is designed for use with or without a permanent foundation when attached to the required utilities. The term "manufactured home" does not include a "recreational vehicle."

Masonry – Built-up construction of combination of building units or materials of clay, shale, concrete, glass, gypsum, stone, or other approved units bonded together with or without mortar or grout or other accepted methods of joining.

Mass casualty – Incident in which the number of victims exceeds the capability of the emergency management system to manage the incident effectively.

Maximum Magnitude Earthquake (Mmax) – The highest magnitude earthquake a fault is capable of producing based on physical limitations, such as the length of the fault or fault segment.

Maximum Probable Earthquake (MPE) – The design size of the earthquake expected to occur within a time frame of interest, for example within 30 years or 100 years, depending on the purpose, lifetime or importance of the facility. Magnitude/frequency relationships are based on historic seismicity, fault slip rates, or mathematical models. The more critical the facility, the longer the time period considered.

Mediterranean climate – The climate characteristic of the Mediterranean region and most of California, characterized by hot, dry summers, and cool, wet winters.

Metamorphic rock – A rock whose original mineralogy, texture, or composition has been changed due to the effects of pressure, temperature, or the gain or loss of chemical components.

Mean sea level (MSL) – Average height of the sea for all stages of the tide, usually determined from hourly height observations over a 19-year period on an open coast or in adjacent waters having free access to the sea. See *National Geodetic Vertical Datum*.

Microburst – A very localized zone of sinking air, less than 2.5 miles in diameter, producing damaging, straight-line, divergent winds at or near the ground surface lasting 2 to 5 minutes.

Mitigation – Any action taken to reduce or permanently eliminate the long-term risk to life and property from natural hazards.

Mitigation Directorate – Component of *Federal Emergency Management Agency* directly responsible for administering the flood hazard identification and *floodplain management* aspects of the *National Flood Insurance Program*.

Moderate earthquake – Capable of causing considerable to severe damage, generally in the range of Magnitude 5.0 to 6.0 (Modified Mercalli Intensity <VI), but highly dependent on rupture mechanism, depth of earthquake, and location relative to urban center, etc.

Modified Mercalli Intensity – A qualitative measure of the size of an earthquake based on people's description of how strongly the earthquake was felt, and the damage it caused to the built environment. The scale has 12 divisions, ranging from I (felt by only a very few people) to XII (total damage).

Mutual Aid Agreement – A reciprocal aid agreement between two or more agencies that defines what resources each will provide to the other in response to certain predetermined types of emergencies. Mutual aid response is provided upon request.

National Fire Protection Association (NFPA) – A group that issues fire and safety standards for industry and emergency responders.

National Flood Insurance Program (NFIP) – Federal program created by Congress in 1968 that makes *flood* insurance available in communities that enact and enforce satisfactory *floodplain management regulations*.

National Geodetic Vertical Datum (NGVD) – Datum established in 1929 and used as a basis for measuring flood, ground, and structural elevations, previously referred to as Sea Level Datum or *Mean Sea Level*. The *Base Flood Elevations* shown on most of the *Flood Insurance Rate Maps* issued by the *Federal Emergency Management Agency* are referenced to NGVD or, more recently, to the *North American Vertical Datum*.

Near-field earthquake – Used to describe a local earthquake within approximately a few fault zone widths of the causative fault which is characterized by high frequency waveforms that are destructive to above-ground utilities and short period structures (less than about two or three stories).

New construction – For the purpose of determining flood insurance rates under the *National Flood Insurance Program*, *structures* for which the start of construction commenced on or after the effective date of the initial *Flood Insurance Rate Map* or after December 31, 1974, whichever is later, including any subsequent improvements to such structures. (See *Post-FIRM structure*.) For *floodplain management* purposes, new construction means *structures* for which the *start of construction* commenced on or after the effective date of a *floodplain management regulation* adopted by a community and includes any subsequent improvements to such structures.

Non-coastal A zone – The portion of the *Special Flood Hazard Area* in which the principal source of *flooding* is runoff from rainfall, snowmelt, or a combination of both. In non-coastal A zones, *flood* waters may move slowly or rapidly, but waves are usually not a significant threat to buildings. See *A zone* and *coastal A zone*. (Note: the *National Flood Insurance Program* regulations do not differentiate between non-coastal A zones and *coastal A zones*.)

Non-load-bearing wall – Wall that does not support vertical loads other than its own weight. See *Load-bearing wall*.

North American Vertical Datum (NAVD) – Datum used as a basis for measuring flood, ground, and structural elevations. NAVD is used in many recent *Flood Insurance Studies* rather than the *National Geodetic Vertical Datum*.

Oblique-reverse fault – A fault that combines some strike-slip motion with some dip-slip motion in which the upper block, above the fault plane, moves up over the lower block.

Offset ridge – A ridge that is discontinuous on account of faulting.

Offset stream – A stream displaced laterally or vertically by faulting.

One hundred (100)-year flood – See *Base flood*.

Orthoclase – One of the most common rock-forming minerals; colorless, white, cream-yellow, flesh-reddish, or grayish in color.

Paleoseismic – Pertaining to an earthquake or earth vibration that happened decades, centuries, or millennia ago.

Peak flood – The highest discharge or stage value of a flood.

Peak Ground Acceleration (PGA) – The greatest amplitude of acceleration measured for a single frequency on an earthquake accelerogram. The maximum horizontal ground motion generated by an earthquake. The measure of this motion is the acceleration of gravity (equal to 32 feet per second squared, or 980 centimeter per second squared), and generally expressed as a percentage of gravity.

Pedogenic – Pertaining to soil formation.

Pegmatite – An igneous rock with extremely large grains, more than a centimeter in diameter.

Perched ground water – Unconfined ground water separated from an underlying main body of ground water by an unsaturated zone.

Perennial Stream – A stream that flows continuously throughout the year.

Plagioclase – One of the most common rock forming minerals.

Playa – Term used in the Southwestern US to describe a flat-floored, typically unvegetated area composed of thin, stratified sheets of fine clay, silt or sand that represent the bottom or central part of a shallow, completely closed or undrained desert lake basin where water accumulates after a rainstorm and quickly evaporates, leaving behind deposits of soluble salts.

Plutonic – Pertaining to igneous rocks formed at great depth.

Plywood – Wood structural panel composed of plies of wood veneer arranged in cross-aligned layers. The plies are bonded with an adhesive that cures on application of heat and pressure.

Pore pressure – The stress transmitted by the fluid that fills the voids between particles of a soil or rock mass.

Post foundation – Foundation consisting of vertical support members set in holes and backfilled with compacted material. Posts are usually made of wood and usually must be braced. Posts are also known as columns, but columns are usually made of concrete or masonry.

Post-FIRM structure – For purposes of determining insurance rates under the *National Flood Insurance Program*, structures for which the *start of construction* commenced on or after the effective date of an initial *Flood Insurance Rate Map* or after December 31, 1974, whichever is later, including any subsequent improvements to such structures. This term should not be confused with the term *new construction* as it is used in *floodplain management*.

Potentially active fault – According to the Alquist-Priolo Earthquake Fault Zone Act guidelines, a fault showing evidence of movement within the last 1.6 million years but that has not been shown conclusively whether or not it has ruptured in the past about 11,000 years ago. The U.S. Geological Survey considers a fault potentially active if it has moved in the time period between about 11,000 years ago (the Holocene) and 750,000 years ago, and that is thought capable of generating damaging earthquakes.

Precast concrete – Structural concrete element cast elsewhere than its final position in the structure. See *Cast-in-place concrete*.

Primary fault rupture - Fissuring and displacement of the ground surface along a fault that breaks in an earthquake.

Project – A development application involving zone changes, variances, conditional use permits, tentative parcel maps, tentative tract maps, and plan amendments.

Quartzite – A metamorphic rock consisting mostly of quartz.

Quartz monzonite – A plutonic rock containing major plagioclase, orthoclase and quartz; with increased orthoclase it becomes a granite.

Quaternary – The second period of the Cenozoic era, consisting of the Pleistocene and Holocene epochs; covers the last approximately 1.6 to 2 million years.

Rain shadow – A reduction in precipitation in an area on the leeward side of a mountain or range of mountains, caused by the release of moisture on the windward side.

Resonance – Amplification of ground motion frequencies within bands matching the natural frequency of a structure and often causing partial or complete structural collapse; effects may demonstrate minor damage to single-story residential structures while adjacent 3- or 4-story buildings may collapse because of corresponding frequencies, or vice versa.

Recurrence interval – The time between earthquakes of a given magnitude, or within a given magnitude range, on a specific fault or within a specific area.

Reinforced concrete – *Structural concrete* reinforced with steel bars.

Remote shutoff – Valve that can be used to shut off the flow of a substance or chemical from a location away from the spill or break.

Response spectra – The range of potentially damaging frequencies of a given earthquake applied to a specific site and for a particular building or structure.

Retrofit – Any change made to an existing structure to reduce or eliminate damage to that structure from flooding, *erosion*, high winds, earthquakes, or other hazards.

Revetment – Facing of stone, cement, sandbags, or other materials placed on an earthen wall or embankment to protect it from *erosion* or *scour* caused by *flood* waters or wave action.

Rhyolite – A group of extrusive igneous rocks, generally exhibiting flow texture, with large crystals (phenocrysts) of quartz and alkali feldspar in a glassy to cryptocrystalline groundmass. The approximate extrusive equivalent of granite.

Ridgetop shattering – An earthquake-induced type of ground failure that occurs along at or along the top of ridges, forming linear, fault-like fissures, and leaving the area looking like it was plowed.

Right-lateral fault – A strike-slip fault across which a viewer would see the block on the opposite side of the fault move to the right.

Riprap – Broken stone, cut stone blocks, or rubble that is placed on slopes to protect them from *erosion* or *scour* caused by *flood* waters or wave action.

Rockfall – Free-falling to tumbling mass of bedrock that has broken off steep canyon walls or cliffs.

Sand boil – An accumulation of sand resembling a miniature volcano or low volcanic mound produced by the expulsion of liquefied sand to the sediment surface. Also called sand blows, and sand volcanoes.

Sandstone – A medium-grained, clastic sedimentary rock composed of abundant rounded or angular fragments of sand size set in a fine-grained matrix and more or less firmly united by a cementing material.

Saturated – Said of the condition in which the interstices of a material are filled with a liquid, usually water.

Scarp – A line of cliffs produced by faulting or by erosion. The term is an abbreviated form of escarpment.

Schist – A metamorphic rock characterized by a preferred orientation in grains resulting in the rock's ability to be split into thin flakes or slabs.

Scour – Removal of soil or fill material by the flow of *flood* waters. The term is frequently used to describe storm-induced, localized conical erosion around pilings and other foundation supports where the obstruction of flow increases turbulence. See *Erosion*.

Secondary fault rupture - Ground surface displacements along faults other than the main traces of active regional faults.

Sediment – Solid fragmental material that originates from weathering of rocks and is transported or deposited by air, water, ice, or that accumulates by other natural agents, such as chemical precipitation from solution, and that forms in layers on the Earth's surface in a loose, unconsolidated form.

Seiche – A free or standing-wave oscillation of the surface of water in an enclosed or semi-enclosed basin (such as a lake, bay, or harbor), that is initiated chiefly by local changes in atmospheric pressure, aided by winds, tidal currents, and earthquakes, and that continues, pendulum-fashion, for a time after cessation of the originating force.

Seismic Moment – A measure of the size of an earthquake that is associated with the amount of energy released (the force that was necessary to overcome the friction along the fault plane), the area of the fault rupture, and the average amount of slip.

Seismogenic – Capable of producing earthquake activity.

Seismograph – An instrument that detects, magnifies, and records vibrations of the Earth, especially earthquakes. The resulting record is a seismogram.

Shearwall – *Load-bearing wall* or *non-load-bearing wall* that transfers in-plane lateral forces from lateral *loads* acting on a structure to its foundation.

Sheet flow – An overland flow or downslope movement of water taking the form of a thin, continuous film over relatively smooth soil or rocks surfaces and not concentrated into channels larger than rills.

Shutter ridge – That portion of an offset ridge that blocks or "shutters" the adjacent canyon.

Sidehill fill – A wedge of artificial fill typically placed on the side of a natural slope to create a roadway or a level building pad.

Silt – A rock fragment or detrital particle smaller than a very fine sand grain and larger than coarse clay, having a diameter in the range of 1/256 to 1/16 mm (4-62 microns, or 0.00016-0.0025 in.). An indurated silt having the texture and composition of shale but lacking its fine lamination is called a siltstone.

Slip Rate – The speed at which a fault is moving, typically expressed in millimeters per year (mm/yr), and generally estimated by measuring the amount of offset that has occurred in a given, known amount of time.

Slope ratio – Refers to the angle or gradient of a slope as the ratio of horizontal units to vertical units. For example, in a 2:1 slope, for every two horizontal units, there is a vertical rise of one unit (equal to a slope angle, from the horizontal, of 26.6 degrees).

Slump – A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip surface.

Soft-story building – Building with a story, generally the ground or first floor, lacking adequate strength or toughness due to too few shear walls. Examples of this type of structure include apartments above glass-fronted stores, and buildings perched atop parking garages.

Soil horizon – A layer of soil that is distinguishable from adjacent layers by characteristic physical properties such as structure, color, or texture.

Special Flood Hazard Area (SFHA) – Under the *National Flood Insurance Program*, an area having special *flood*, mudslide (i.e., mudflow) and/or flood-related erosion hazards, and shown on a Flood Hazard Boundary Map or *Flood Insurance Rate Map* as Zone A, AO, A1-A30, AE, A99, AH, V, V1-V30, VE, M or E.

Storage capacity – Dam storage measured in acre-feet or decameters, including dead storage.

Strike-slip fault – A fault with a vertical to sub-vertical fault surface that displays evidence of horizontal and opposite displacement.

Structural concrete – All concrete used for structural purposes, including *plain concrete* and *reinforced concrete*.

Structural engineer – A licensed civil engineer certified by the State as qualified to design and supervise the construction of engineered structures.

Structural fill – Fill compacted to a specified density to provide structural support or protection to a *structure*. See *Fill*.

Structure – Something constructed, such as a building, or part of one. For *floodplain management* purposes under the *National flood Insurance Program*, a walled and roofed building, including a gas or liquid storage tank, that is principally above ground, as well as a manufactured home. For insurance coverage purposes under the NFIP, structure means a walled and roofed building, other than a gas or liquid storage tank, that is principally above ground and affixed to a permanent site, as well as a *manufactured home* on a permanent foundation. For the latter purpose, the term includes a building while in the course of construction, alteration, or repair, but does not include building materials or supplies intended for use in such construction, alteration, or repair, unless such materials or supplies are within an enclosed building on the premises.

Subsidence – The sudden sinking or gradual downward settling of the Earth's surface with little or no horizontal motion.

Swale – In hillside terrace, a shallow drainage channel, typically with a rounded depression or "hollow" at the head.

Talus – The cone-shaped accumulation of angular fragments of rock or soil at the base of a cliff that has experienced rockfalls.

Tectonic plate – Any of several large pieces, or blocks, of the Earth's lithosphere that are slowly moving relative to each other as part of the process called plate tectonics.

Thrust fault – A fault, with a relatively shallow dip, in which the upper block, above the fault plane, moves up over the lower block.

Transform system – A system in which faults of plate-boundary dimensions transform into another plate-boundary structure when it ends.

Transpression – In crustal deformation, an intermediate stage between compression and strike-slip motion; it occurs in zones with oblique compression.

Tsunami – Great sea wave produced by submarine earth movement, volcanic eruption, oceanic meteor impact, or underwater nuclear explosion.

Unconfined aquifer – Aquifer in which the upper surface of the saturated zone is free to rise and fall.

Unconsolidated sediments – A deposit that is loosely arranged or unstratified, or whose particles are not cemented together, occurring either at the surface or at depth.

Undermining – Process whereby the vertical component of erosion or scour exceeds the depth of the base of a building foundation or the level below which the bearing strength of at the foundation is compromised.

Unreinforced Masonry (URM) structure – Building without adequate anchorage of the masonry walls to the roof and floor diaphragms and lack of steel reinforcement, of limited strength and ductility, and as a result, that tends to perform poorly when shaken during an earthquake.

Uplift – Hydrostatic pressure caused by water under a building. It can be strong enough lift a building off its foundation, especially when the building is not properly anchored to its foundation.

Upper bound earthquake – Defined as a 10% chance of exceedance in 100 years, with a statistical return period of 949 years.

Variance – Under the *National Flood Insurance Program*, grant of relief by a community from the terms of a *floodplain management regulation*.

Violation – Under the *National Flood Insurance Program*, the failure of a structure or other development to be fully compliant with the community's *floodplain management regulations*. A *structure* or other *development* without the elevation certificate, other certifications, or other evidence of compliance required in Sections 60.3(b)(5), (c)(4), (c)(10), (d)(3), (e)(2), (e)(4), or (e)(5) of the NFIP regulations is presumed to be in violation until such time as that documentation is provided.

Watershed – A topographically defined region draining into a particular river or lake.

Water surface elevation – Under the *National Flood Insurance Program*, the height, in relation to the *National Geodetic Vertical Datum* of 1929 (or other datum, where specified), of *floods* of various magnitudes and frequencies in the *floodplains* of coastal or riverine areas.

Water table – The upper surface of groundwater saturation of pores and fractures in rock or surficial earth materials.

Water year – The 12-month period from October 1 through September 30 of the following year.

Weather – The short-term state of the air or atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness, or any other meteorologic phenomena.

X zone – Under the *National Flood Insurance Program*, areas where the *flood* hazard is less than that in the *Special Flood Hazard Area*. Shaded X zones shown on recent *Flood Insurance Rate Maps* (B zones on older maps) designate areas subject to inundation by the *500-year flood*. Un-shaded X zones (C zones on older *Flood Insurance Rate Maps*) designate areas where the annual probability of flooding is less than 0.2 percent.